Section 2

ASSESSMENT OF THE PACIFIC COD STOCK IN THE EASTERN BERING SEA AND ALEUTIAN ISLANDS AREA

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EXECUTIVE SUMMARY

Summary of Major Changes

Relative to the November edition of last year's BSAI SAFE report, the following substantive changes have been made in the Pacific cod stock assessment.

Changes in the Input Data

1) Size composition data from the 2001 fisheries were updated and size composition data from the January-August 2002 fisheries were incorporated.
2) Size composition data from the 2002 EBS bottom trawl survey were incorporated.
3) The biomass estimate from the 2002 EBS bottom trawl survey was incorporated (the 2002 estimate of 616,923 t was down about 26% from 2001; the 2001 estimate was up about 57% from 2000).
4) The biomass estimate from the 2002 AI bottom trawl survey was incorporated (the estimate of 82,853 t was down about 39% from 2000 but nearly identical to the 1997 estimate).
5) Catches from 2001 were updated and catches through August, 2002 were incorporated.

Changes in the Assessment Model

Separate selectivity schedules were estimated for the intervals 1978-1988, 1989-1999, and 2000-present. In previous assessments, only two intervals were specified: 1978-1988 and 1989-present.

Changes in Assessment Results

1) The estimated 2003 spawning biomass for the BSAI stock is 423,000 t, essentially unchanged from last year's estimate for 2002 and up about 4% from last year's F_{ABC} projection for 2003.
2) The estimated 2003 total age 3+ biomass for the BSAI stock is 1,680,000 t, up about 9% from last year's estimate for 2002 and up about 3% from last year's $F_{40\%}$ projection for 2003.
3) The recommended 2003 ABC for the BSAI stock is 245,000 t, up about 10% from last year's recommendation for 2002 and up about 15% from last year's F_{ABC} projection for 2003.
4) The estimated 2003 OFL for the BSAI stock is 324,000 t, up about 10% from last year's estimate for 2002.

Responses to Comments of the Scientific and Statistical Committee (SSC)

SSC Comments Specific to the Pacific Cod Assessments

From the December, 2001 minutes: *"Current model configurations estimate fishery selectivity in two time stanzas. Given the regulatory changes of the last two years, the SSC recommends that the stock assessment authors evaluate selectivity to determine if additional divisions are appropriate. We also reiterate our call to attempt to calculate a statistically valid spawner-recruit relationship for this stock."* An alternative model configuration with a separate set of selectivity schedules for years 2000 and beyond is described in the "Model Structure" subsection of the "Analytic Approach" section and evaluated in the "Model Evaluation" section. As in last year's assessment, a provisional stock-recruitment relationship is described in the "Recruitment" subsection of the "Results" section. Additional research, not described in this assessment, has been conducted in support of a new assessment model capable of calculating a statistically valid spawner-recruit relationship for this stock.

SSC Comments on Assessments in General

From the December, 2001 minutes: *"The SSC encourages the use of retrospective analysis of stock abundance trends, (i.e. the sequential deletion of annual input data to check for changes in output trends.) The presence of a sustained retrospective pattern can be a diagnostic of model adequacy."* A retrospective analysis is provided in the "Biomass" subsection of the "Results" section.

INTRODUCTION

Pacific cod (*Gadus macrocephalus*) is a transoceanic species, occurring at depths from shoreline to 500 m. The southern limit of the species' distribution is about 34° N latitude, with a northern limit of about 63° N latitude. Pacific cod is distributed widely over the eastern Bering Sea (EBS) as well as in the Aleutian Islands (AI) area. The resource in these two areas (BSAI) is managed as a single unit. Tagging studies (e.g., Shimada and Kimura 1994) have demonstrated significant migration both within and between the EBS, AI, and Gulf of Alaska (GOA), and genetic studies (e.g., Grant et al. 1987) have failed to show significant evidence of stock structure within these areas. Pacific cod is not known to exhibit any special life history characteristics that would require it to be assessed or managed differently from other groundfish stocks in the EBS or AI areas.

FISHERY

During the early 1960s, a Japanese longline fishery harvested BSAI Pacific cod for the frozen fish market. Beginning in 1964, the Japanese trawl fishery for walleye pollock (*Theragra chalcogramma*) expanded and cod became an important bycatch species and an occasional target species when high concentrations were detected during pollock operations. By the time that the Magnuson Fishery Conservation and Management Act went into effect in 1977, foreign catches of Pacific cod had consistently been in the 30,000-70,000 t range for a full decade. Catches of Pacific cod since 1978 are shown in Table 2.1, broken down by management area, year, fleet sector, and gear type. In 1981, a U.S. domestic trawl fishery and several joint venture fisheries began operations in the BSAI. The foreign and joint venture sectors dominated catches through 1988, but by 1989 the domestic sector was dominant and by 1991 the foreign and joint venture sectors had been displaced entirely. Presently, the Pacific cod stock is exploited by a multiple-gear fishery, including trawl, longline, pot, and jig components.

The history of acceptable biological catch (ABC) and total allowable catch (TAC) levels is summarized and compared with the time series of aggregate (i.e., all-gear, combined area) commercial catches in Table 2.2. From 1980 through 2002, TAC averaged about 75% of ABC, and aggregate commercial catch (excluding 2002, for which a final catch total is not yet available) averaged about 87% of TAC. In 8 of these 23 years (35%), TAC equaled ABC exactly, and in 4 of these 22 years (17%), catch exceeded TAC. Changes in ABC over time are typically attributable to three factors: 1) changes in resource abundance, 2) changes in management strategy, and 3) changes in the stock assessment model. For example, from 1980 through 2002, five different assessment models were used (Table 2.2), though the present model has remained unchanged since 1997.

Historically, the great majority of the BSAI catch has come from the EBS area. During the most recent five-year period (1997-2001), the EBS accounted for an average of about 84% of the BSAI catch.

The catches shown in Tables 2.1 and 2.2 include estimated discards. Recent (2001-2002) discard rates of Pacific cod in the various BSAI target fisheries are summarized in Table 2.3.

For the 2001 and 2002 fisheries, several regulations were adopted in an attempt to mitigate possible fishery impacts on the endangered western population of Steller sea lion (*Eumetopias jubatus*). Some of these regulations were designed to spread the catch of Pacific cod more evenly throughout the year. The table below compares the distribution of catch during the periods January-May (“Per. 1”), June-August (“Per. 2”), and September-December (“Per. 3”) for the 2001 fishery with the average for the preceding three years (for each gear type, the numbers in a given row sum to 1.0):

		Trawl			Longline			Pot		
Area	Year(s)	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3
BS	2001	0.64	0.20	0.16	0.43	0.07	0.50	0.71	0.03	0.26
BS	1998-2000	0.81	0.08	0.11	0.60	0.01	0.39	0.82	0.09	0.09
AI	2001	0.89	0.03	0.08	0.68	0.09	0.23	0.73	0.00	0.27
AI	1998-2000	0.89	0.02	0.09	0.69	0.02	0.29	0.89	0.04	0.07

DATA

This section describes data used in the current assessment. It does not attempt to summarize all available data pertaining to Pacific cod in the BSAI.

Commercial Catch Data

Catch Biomass

Catches (including estimated discards) taken in the EBS since 1978 are shown in Table 2.4, broken down by the three main gear types and intra-annual periods consisting of the months January-May, June-August, and September-December. This particular division, which was suggested by participants in the EBS fishery, is intended to reflect actual intra-annual differences in fleet operation (e.g., fishing operations during the spawning period may be different than at other times of year). In years for which estimates of the distribution by gear or period were not available, proxies based on other years' distributions were used.

Catch Size Composition

Fishery size compositions are presently available, by gear, for the years 1978 through the first part of 2002. As in all assessments since 1997, size composition data from trawl catches sampled on shore were not included in the set of input data, because a comparison of cruises for which both at-sea and shoreside size composition samples were available showed that, in the case of trawl catches, the shoreside data typically contained a smaller proportion of small fish than the at-sea data, indicating that these data may reflect post-discard landings rather than the entire catch. For ease of representation and analysis, length frequency data for Pacific cod can usefully be grouped according to the following set of 25 intervals or "bins," with the upper and lower boundaries shown in cm:

Bin Number:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Lower Bound:	9	12	15	18	21	24	27	30	33	36	39	42	45	50	55	60	65	70	75	80	85	90	95	100	105
Upper Bound:	11	14	17	20	23	26	29	32	35	38	41	44	49	54	59	64	69	74	79	84	89	94	99	104	115

Total length sample sizes for each year, gear, and period are shown in Table 2.5. The collections of relative length frequencies are shown by year, period, and size bin for the pre-1989 trawl fishery in Table 2.6, the pre-1989 longline fishery in Table 2.7, the post-1988 trawl fishery in Table 2.8, the post-1988 longline fishery in Table 2.9, and the pot fishery in Table 2.10.

Survey Data

EBS Shelf Trawl Survey

The relative size compositions from trawl surveys of the EBS shelf conducted by the Alaska Fisheries Science Center since 1979 are shown in Table 2.11, using the same length bins defined above for the commercial catch size compositions. Information regarding the absolute numbers of fish measured at each length are available only for the years 1986-1987 and 1990-2002. For all other years, only relative numbers of measured fish are available. The total sample sizes from the years 1986-1987 and 1990-2002 are shown below:

Year:	1986	1987	1990	1991	1992	1993	1994	1995
Sample Size:	15376	10609	5628	7228	9601	10404	13922	9216

Year:	1996	1997	1998	1999	2000	2001	2002
Sample Size:	9348	9169	9583	11699	12564	19750	12238

Estimates of total abundance (both in biomass and numbers of fish) obtained from the trawl surveys are shown in Table 2.12, together with the standard errors and upper and lower 95% confidence intervals (CI) for the biomass estimates. Survey results indicate that biomass increased steadily from 1978 through 1983, then remained relatively constant from 1983 through 1989. The highest biomass ever observed by the survey was the 1994 estimate of 1,368,109 t. Following the high observation in 1994, the survey biomass estimate declined steadily through 1998. The survey biomass estimates remained in the 520,000-620,000 t range from 1998 through 2002, except for 2001, when the estimate was 830,479 t. The 2002 estimate was 616,923 t.

In terms of numbers (as opposed to biomass), the record high was observed in 1979, when the population was estimated to include over 1.5 billion fish. The 1994 estimate of population numbers was the second highest on record. After the peak in 1994, numerical declines were observed through 1997, paralleling the biomass time trend. The survey estimate of population numbers remained in the 480-570 million fish range from 1997 through 2002, except for 2001, when the estimate was 980 million fish. The 2002 estimate was 564 million fish.

Both the biomass and numerical abundance estimates from the 2001 survey appear likely to be overestimates, given the magnitudes of the implied increases relative to the 2000 survey (57% and 104%, respectively) and the fact that the 2002 estimates were much more in line with the preceding estimates.

Aleutian Trawl Survey

Biomass estimates for the Aleutian Islands region were derived from U.S.-Japan cooperative trawl surveys conducted during the summers of 1980, 1983, and 1986, and by U.S. trawl surveys of the same area in 1991, 1994, 1997, 2000, and 2002. These surveys covered both the Aleutian management area (170 degrees east to 170 degrees west) and a portion of the Bering Sea management area ("Southern Bering Sea") not covered by the EBS shelf surveys. In 2000, the results from the 1991, 1994, and 1997 surveys were re-calibrated, giving new estimates of biomass for those years. The current time series of biomass estimates from both portions of the Aleutian survey area are shown together with their sum below (all figures are in t):

Year	Aleutian Management Area	Southern Bering Sea	Aleutian Survey Area
1980	52,070	74,373	126,443
1983	113,148	45,624	158,772
1986	172,625	42,298	214,923
1991	180,904	8,286	189,190
1994	153,026	31,084	184,109
1997	72,674	10,742	83,416
2000	126,918	9,157	136,075
2002	73,252	9,601	82,853

As in previous assessments of Pacific cod in the BSAI, a weighted average formed from EBS and Aleutian survey biomass estimates is used in the present assessment to provide a conversion factor which can be used to translate model projections of EBS catch and biomass into BSAI equivalents. Because the assessment model is configured to represent the portion of the Pacific cod population inhabiting the EBS survey area (as opposed to the more extensive EBS *management* area), it seems appropriate to use the biomass estimates from the entire Aleutian survey area (as opposed to the less extensive Aleutian *management* area) to inflate model projections of EBS catch and biomass. Weighted averages of the biomass estimates from the entire Aleutian survey area and their EBS survey area counterparts indicate that, on average, the ratio of Pacific cod biomass in the combined BS and AI management areas to that in the EBS survey area is about 1.17. Because the 83-112 net (with no roller gear) used in the EBS survey generally tends the bottom better than the polyethylene Noreastern net (with roller gear) used in the AI survey, this ratio should tend to err on the conservative side.

Survey Removals

The amount of Pacific cod removed from the population as a result of NMFS hydroacoustic, longline, and bottom trawl survey operations is summarized for the EBS and AI in Table 2.13. In all years, the magnitude of these removals has been negligible in comparison to the commercial catch (the average ratio of survey removals to commercial removals in the EBS over the period 1978-2002 was approximately 0.001).

Length at Age, Weight at Length, and Maturity at Length

The set of reliable length at age data for BSAI Pacific cod has been small for the past several years and such data are used only sparingly in this assessment. The otoliths examined from fish sampled during EBS shelf trawl surveys provide the following data regarding the relationship between age and length and the amount of spread around that relationship (lengths, in cm, were measured during summer, and ages are back-dated to January 1):

Age group:	1	2	3	4	5	6	7	8	9	10	11	12
Average length:	19	29	37	48	57	65	73	79	82	84	86	89
St. dev. of length:	3.5	5.3	5.0	4.9	4.2	3.7	4.0	5.4	7.4	5.8	7.4	7.7

Although the supply of reliable length at age data has been severely limited in the past, it now appears likely that such data will become much more available in the future. Studies at the Alaska Fisheries Science Center have resulted in an ageing methodology for Pacific cod that gives reliable age determinations (Roberson 2001), and production ageing of this species has recently begun (Delsa Anderl, pers. commun.).

Weight measurements taken during summer bottom trawl surveys since 1975 yield the following data regarding average weights (in kg) at length, grouped according to size composition bin (as defined under "Catch Size Composition" above):

Bin Number:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Ave. weight:	0.0	0.0	0.0	0.1	0.1	0.2	0.2	0.3	0.4	0.6	0.7	0.9	1.2	1.6	2.2	2.9	3.5	4.6	5.6	7.0	8.4	10.1	11.8	11.0	15.0

From 1984 through 1994, assessments of EBS Pacific cod used a maturity schedule based on a logistic function with an inflection at about 61 cm. This schedule was based on a survey sample of fish taken during the 1981-1982 field seasons (see review provided by Thompson and Methot 1993). To update the maturity schedule for Pacific cod, a sampling program was initiated in 1993, using commercial fishery observers. So far, data have been analyzed for 1994 only. These data consist of observers' visual determinations regarding the spawning condition of 2312 females taken in the EBS fishery. Of these 2312 females, 231 were smaller than 42 cm (the lower boundary of length bin 12). None of these sub-42 cm fish were mature. The observed proportions of mature fish in the remaining length bins, together with the numbers of fish sampled in those length bins, are shown below (bins are defined under "Catch Size Composition" above):

Bin number:	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Prop. mature:	0.03	0.05	0.14	0.19	0.28	0.53	0.69	0.82	0.89	0.94	0.94	0.91	0.89	1.00
Sample size:	39	122	226	313	295	300	320	177	103	70	50	35	19	12

ANALYTIC APPROACH

Model Structure

This year's base model structure is identical to the base model structure used in all assessments of the EBS Pacific cod stock since 1997 (Thompson and Dorn 1997). Beginning with the 1993 SAFE report (Thompson and Methot 1993), a length-structured Synthesis model (Methot 1986, 1989, 1990, 1998) has formed the primary analytical tool used to assess the EBS Pacific cod stock. Synthesis is a program that uses the parameters of a set of equations governing the assumed dynamics of the stock (the "model parameters") as surrogates for the parameters of statistical distributions from which the data are assumed to be drawn (the "distribution parameters"), and varies the model parameters systematically in the direction of increasing likelihood until a maximum is reached. The overall likelihood is the product of the likelihoods for each of the model components. Each likelihood component is associated with a set of data assumed to be drawn from statistical distributions of the same general form (e.g., multinomial, lognormal, etc.). Typically, likelihood components are associated with data sets such as catch size (or age) composition, survey size (or age) composition, and survey biomass.

The Synthesis program permits each data time series to be divided into multiple segments, or "eras," resulting in a separate set of parameter estimates for each era. In the base model for the EBS Pacific cod assessment, for example, the survey size composition and survey biomass time series have traditionally been split into pre-1982 and post-1981 eras to account for the effects of a change in the trawl survey gear that occurred in 1982. Also, to account for possible differences in selectivity between the mostly foreign (also joint venture) and mostly domestic fisheries, the fishery size composition time series in the base model has traditionally been split into pre-1989 and post-1988 eras. A minor modification of the base model was suggested by the SSC at its December, 2001 meeting, namely, that consideration be given to dividing the domestic era into pre-2000 and post-1999 segments. Two models are therefore considered in this year's assessment: Model 1 is the base model, unchanged since 1997. Model 2 is identical to Model 1, except that an additional set of fishery selectivity schedules was estimated for the post-1999 era.

Symbols used in the stock assessment model are listed in Table 2.14 (note that this list applies to the stock assessment model only, and does not include all symbols used elsewhere in this document). Synthesis uses a total of 16 dimensional constants, special values of indices, and special values of continuous variables, all of which are listed on the first page of Table 2.14. The values of these quantities are not estimated statistically, in the strict sense, but are typically set by assumption or as a matter of structural specification. The values of these constants, indices, and variables are listed in Table 2.15, with a brief rationale given for each value used. In contrast to the quantities whose values are specified in Table 2.15, Synthesis uses a large number of parameters that are estimated statistically (though the estimation itself may not necessarily take place within Synthesis). For ease of reference, capital Roman letters are used to designate such "Synthesis parameters," which are listed on the second page of Table 2.14.

Functional representations of population dynamics are given in Appendix 2A, using the symbols defined in Table 2.14. It should be noted that, while the equations given in Appendix 2A are generally similar to those used in Synthesis, they may differ in detail. Also, only a subset of the equations actually used by Synthesis is shown. Basically, enough equations are shown to illustrate at least one use for each of the symbols shown in Table 2.14.

The assessments conducted during the period 1997-1999 (Thompson and Dorn 1997, Thompson and Dorn 1998, Thompson and Dorn 1999) used approximate Bayesian methods to address uncertainty surrounding the true values of two key model parameters, the natural mortality rate M and the survey catchability coefficient Q. Due to limitations of the Synthesis software, a type of meta-analysis was used to implement the Bayesian portion of those assessments. This meta-analysis involved fitting a pair of bivariate distributions to the log-likelihood maxima and projected $F_{40\%}$ catches returned from a very large number of individual model runs, each of which held M and Q constant at a unique pair of values. The pairs of M and Q values corresponded to points placed at regularly spaced intervals within a grid spanning the 95% confidence ellipse of the fitted bivariate log-likelihood surface. The purpose of the Bayesian meta-analysis was to recommend an ABC that accounted for parameter uncertainty in an appropriately risk-averse manner. This was accomplished by setting the recommended ABC equal to the geometric mean of the catch distribution corresponding to the product of the catch profile and the posterior distribution. However, the Bayesian meta-analysis was always extremely labor intensive. In the course of conducting the 2000 stock assessment (Thompson and Dorn 2000), it therefore seemed prudent to seek an efficient shortcut. Looking back at the results of the 1997-1999 stock assessments, it appeared that the ratio between the recommended F_{ABC} emerging from the Bayesian meta-analysis and the $F_{40\%}$ estimate emerging from the base model was converging over time. The average value of this ratio over the 1997-1999 period was 0.86, with a 1999 value of 0.87. Interestingly, identical three-year average and 1999 values were obtained in the 1997-1999 assessments of the GOA Pacific cod stock (Thompson et al. 1997, Thompson et al. 1998, Thompson et al. 1999). Because the 1999 value represented the most recent estimate and was approximately equal to the 1997-1999 average, the 2000 stock assessment multiplied this value (0.87) by the maximum permissible F_{ABC} to obtain the recommended F_{ABC}. The resulting ABC recommendation was accepted by the SSC and the Council. The same procedure was used in the 2001 assessment (Thompson and Dorn 2001) and is retained in the present assessment as well, thereby eliminating the need to re-perform the Bayesian meta-analysis.

Parameters Estimated Independently

Table 2.16 divides the set of Synthesis parameters into two parts, the first of which lists those parameters that were estimated independently (i.e., outside of Synthesis), and the second of which lists those parameters that were estimated conditionally (i.e., inside of Synthesis). This section describes the estimation of parameters in the first part of Table 2.16.

Natural Mortality

The natural mortality rate was estimated independently of other parameters at a value of 0.37. This value was used in the present assessment for the following reasons: 1) it was derived as the maximum likelihood estimate of *M* in the 1993 BSAI Pacific cod assessment, 2) it has been used to represent *M* in all BSAI Pacific cod assessments since 1993 and in all GOA Pacific cod assessments except one since 1994, 3) it was explicitly accepted by the SSC for use as an estimate of *M* in the GOA Pacific cod assessment (SSC minutes, December, 1994), and 4) it lies well within the range of previously published estimates of *M* shown below:

Area	Author	Year	Value
Eastern Bering Sea	Low	1974	0.30-0.45
	Wespestad et al.	1982	0.70
	Bakkala and Wespestad	1985	0.45
	Thompson and Shimada	1990	0.29
	Thompson and Methot	1993	0.37
Gulf of Alaska	Thompson and Zenger	1993	0.27
	Thompson and Zenger	1995	0.50
British Columbia	Ketchen	1964	0.83-0.99
	Fournier	1983	0.65

Trawl Survey Catchability

The trawl survey catchability coefficient was estimated independently of other parameters at a value of 1.0. This value was used in the present assessment mostly because it has been used in all previous assessments. Also, preliminary results of recent experimental work conducted in the EBS by the Alaska Fisheries Science Center's Resource Assessment and Conservation Engineering Division tend to confirm that this is a reasonable value (David Somerton, pers. commun.).

Weight at Length

Parameters (Table 2.14) governing the relationship between weight and length (Appendix 2A) were estimated by log-log regression from the available data (see "Data" above), giving the following values (weights are in kg, lengths in cm): $W_1 = 4.36 \times 10^{-6}$, $W_2 = 3.242$.

Length at First Age of Survey Observation

Assuming that the first age at which Pacific cod are seen in the trawl survey (α_1, Table 2.14) is approximately 1.5 years, the length at this age (L_1 , Table 2.14) as estimated to be 15.8 cm by averaging the lengths corresponding to the first mode greater than or equal to 14 cm (bin 2) from each of the five most recent survey size compositions.

Variability in Length at Age

Parameters (Table 2.14) governing the amount of variability surrounding the length-at-age relationship (Appendix 2A) were estimated directly from the observed standard deviations in the available length-at-age data (see "Data" above), giving the following values (in cm): $X_1 = 3.5$, $X_2 = 7.7$. Estimation of these two parameters constituted the only use of age data in the present assessment.

Maturity at Length

Maximum likelihood estimates of the parameters (Table 2.14) governing the female maturity-at-length schedule (Appendix 2A) were obtained using the method described by Prentice (1976), giving the following values: $P_1 = 0.142$, $P_2 = 67.1$ cm. The variance-covariance matrix of the parameter estimates gave a standard deviation of 0.006 for the estimate of P_1, a standard deviation of 0.39 cm for the estimate of P_2, and a correlation of -0.154 between the estimates of the two parameters.

Parameters Estimated Conditionally

Those Synthesis parameters that are estimated internally are listed in the second part of Table 2.16. The estimates of these parameters are conditional on each other, as well as on those listed in the first part of the table and discussed in the preceding section (i.e., those Synthesis parameters that are estimated independently).

Likelihood Components

As noted in the "Model Structure" section, Synthesis is a likelihood-based framework for parameter estimation which allows several data components to be considered simultaneously. In this assessment, four fishery size composition likelihood components were included: the January-May ("early") trawl fishery, the June-December ("late") trawl fishery, the longline fishery, and the pot fishery. In addition to the fishery size composition components, likelihood components for the size composition and biomass trend from the bottom trawl survey were included in the model.

The Synthesis program allows the modeler to specify "emphasis" factors that determine which components receive the greatest attention during the parameter estimation process. As in previous assessments, each component was given an emphasis of 1.0 in the present assessment.

Use of Size Composition Data in Parameter Estimation

Size composition data are assumed to be drawn from a multinomial distribution specific to a particular year, gear/fishery, and time period within the year. In the parameter estimation process, Synthesis weights a given size composition observation (i.e., the size frequency distribution observed in a given year, gear/fishery, and period) according to the emphasis associated with the respective likelihood component and the sample size specified for the multinomial distribution from which the data are assumed to be drawn. In developing the model upon which Synthesis was originally based, Fournier and Archibald (1982) suggested truncating the multinomial sample size at a value of 400 in order to compensate for contingencies which cause the sampling process to depart from the process that gives rise to the multinomial distribution. As in previous assessments, the present assessment uses a multinomial sample size equal to the square root of the true sample size, rather than the true sample size itself. Given the true sample sizes observed in the present assessment, this procedure tends to give values somewhat below 400 while still providing the Synthesis program with usable information regarding the appropriate effort to devote to fitting individual samples. Multinomial sample sizes derived by this procedure for the commercial fishery size compositions are shown in Table 2.17. In the case of survey size composition data, the square root assumption was also used, except that it was necessary to assume a true sample size for the years 1979-1985 and 1988-1989, years for which such measures are unavailable (see "Trawl Survey Data" above). For those years, a true sample size of 10,000 fish was assumed (giving a multinomial sample size of 100), which approximates the average of the 10 known true sample sizes from the years 1986-1997. For the years 1986-1987 and 1990-2002, the square roots (SR) of the true survey sample sizes are shown below:

Year:	1986	1987	1990	1991	1992	1993	1994	1995
SR(sample size):	124	103	75	85	98	102	118	96

Year:	1996	1997	1998	1999	2000	2001	2002
SR(sample size):	97	96	98	108	112	141	111

Use of Survey Biomass Data in Parameter Estimation

Each year's survey biomass datum is assumed to be drawn from a lognormal distribution specific to that year. The model's estimate of survey biomass in a given year serves as the geometric mean for that year's lognormal distribution, and the ratio of the survey biomass datum's standard error to the survey biomass datum itself serves as the distribution's coefficient of variation.

MODEL EVALUATION

As discussed under "Model Structure" above, two models are focused upon in this assessment: Model 1 is the base model, unchanged since 1997. Model 2 is identical to Model 1, except that an additional set of fishery selectivity schedules was estimated for the post-1999 era, as requested by the SSC.

Evaluation Criteria

Four criteria will be used to evaluate the models developed in the present assessment: 1) the effective sample sizes of the size composition data, 2) the root mean squared error (RMSE) of the fit to the survey biomass data, 3) Akaike's Information Criterion (AIC), and 4) the overall reasonableness of the results.

Effective Sample Size

Once maximum likelihood estimates of the model parameters have been obtained, Synthesis computes an "effective" sample size for the size composition data specific to a particular year, gear/fishery, and time period within the year. Roughly, the effective sample size can be interpreted as the multinomial sample size that would typically be required in order to produce the given fit. More precisely, it is the sample size that sets the sum of the marginal variances of the proportions implied by the multinomial distribution equal to the sum of the squared differences between the sample proportions and the estimated proportions (McAllister and Ianelli 1997). As a function of a multinomial random variable, the effective sample size has its own distribution. The harmonic mean of the distribution is equal to the true sample size in the multinomial distribution. Thus, if the effective sample size is less than the true sample size in the multinomial distribution, it is reasonable to conclude that the fit is not as good as expected. The following table shows the average of the input sample sizes and the average effective sample sizes for each of the size composition components in the two models (in each column, the average is computed with respect to all years and periods present in the respective time series):

Size composition	Ave. effective sample size		Ave. input	Effective size / input size	
likelihood component	*Model 1*	*Model 2*	sample size	*Model 1*	*Model 2*
Early-season trawl fishery	183	270	197	0.93	1.37
Late-season trawl fishery	76	77	45	1.69	1.72
Longline fishery	279	304	190	1.47	1.60
Pot fishery	242	238	115	2.11	2.07
Pre-1982 survey	88	85	100	0.88	0.85
Post-1981 survey	160	161	103	1.55	1.56
All	202	223	138	1.47	1.62

Note: True sample sizes for the survey are available only for the years 1986-1987 and 1990-2001. For all other years, a value of 10,000 (square root = 100) was assumed.

Both models produce average effective samples considerably larger than the average input values for most size composition components. Both models produce a ratio less than 1.0 for the pre-1982 survey component. However, this result is not particularly meaningful because the true sample sizes for those years are unknown. Model 1 also produces a ratio less than 1.0 for the early-season trawl fishery component. Model 1 produces a higher ratio than Model 2 for two components (longline fishery and pre-1982 survey), whereas Model 2 produces a higher ratio than Model 1 for the other four components (early-season trawl fishery, late-season trawl fishery, pot fishery, and post-1981 survey). Model 2 also produces a higher overall ratio (1.62) than Model 1 (1.47).

Observed and estimated size compositions in the January-May fisheries in 2000, 2001, and 2002 are compared for Model 1 in Figures 2.1, 2.2, and 2.3; and for Model 2 in Figures 2.4, 2.5, and 2.6. Observed and estimated size compositions from the three most recent bottom trawl surveys are compared for Model 1 in Figure 2.7 and Model 2 in Figure 2.8.

Fit to Survey Biomass Data

The root-mean-squared value of the lognormal "sigma" parameter in the survey biomass data is 0.096. The log-scale RMSEs from both models are about twice this value. The log-scale RMSE from Model 1 is 0.191, slightly lower than Model 2's value of 0.199. The inability of either model to achieve a log-scale RMSE close to the root-mean-squared-sigma may indicate that simple haul-to-haul sampling variability underestimates the true variability of the survey biomass data.

Akaike's Information Criterion

AIC is an information-theoretic measure which can be used as a practical guide to model selection (Burnham and Anderson 1998). For model i with k parameters, the AIC is defined as follows:

$AIC_i = -2\ln(\max(\text{likelihood}_i)) + 2k.$

When comparing two nested models (i.e., where one model contains the other as a special case), the model with the higher AIC is better supported by the data. Thus, when used to compare models, only the difference between AIC values is important. Model 2 has 28 more parameters than Model 1 (four additional sets of fishery-specific selectivity parameters, with seven parameters each), so Model 2 is better supported by the data if, following a bit of algebra, the following relationship holds:

$\ln(\max(\text{likelihood}_2))-\ln(\max(\text{likelihood}_1) > 28$,

whereas Model 1 is better supported by the data if the direction of the above inequality is reversed.

As it turns out, the difference between the maximum log likelihood for Model 2 and the maximum log likelihood for Model 1 in this assessment is 93.8. Therefore, the comparative AIC values indicate that Model 2 is better supported by the data. However, it should be remembered that previous explorations of alternative models for this stock (e.g., Thompson and Dorn 1999) have suggested the existence of subtle difficulties in the way the likelihood is specified for these models, in which case AIC may not be completely reliable as an indicator of support.

Overall Reasonableness of Results

The two models gave virtually identical estimates of length-at-age parameters K and L_2 (L_1 was estimated independently, and thus did not vary with choice of model), as shown below:

Parameter	Model 1	Model 2
K	0.219	0.215
L_2	93.3	93.9

Model-specific estimates of fishing mortality rates $F_{g,y,i}$, recruitments R_y and initial numbers at age N_a, and selectivity parameters $S_{1\text{-}7,g,e(y|g)}$ are shown in Tables 2.18, 2.19, and 2.20, respectively. Again, estimated parameter values were very similar between the two models.

Model-specific estimates of age 3+ biomass, spawning biomass, and survey biomass are shown in Table 2.21 and Figure 2.9. Here, too, results between the two models were very similar.

Given the high degree of similarity between the two models with respect to all of the above measures, it seems fair to conclude that the results from the two models are equally reasonable. It is important to remember that the structural differences between the two models are relatively minor, so it is not surprising that they should give similar results. It should be noted that "reasonableness" has been used here simply as a means to compare models with each other. At its November, 2001 meeting, the BSAI Groundfish Plan Team raised a question regarding another type of "reasonableness," namely whether the model's selectivity estimates were reasonable *in principle*. This question is addressed in Appendix 2B.

Selection of Final Model

One of the main purposes of stock assessments such as the present one is to provide reference estimates of historic biomass trends, target and limit harvest rates, and biomass projections. It is therefore convenient to choose a single model which can be used to generate a set of such reference estimates. Based on the evaluation criteria described above, the evidence is not completely one-sided. The overall results from the two models appear equally reasonable. Of the other three model evaluation criteria, Model 1 performed better than Model 2 with respect to only one, the fit to the survey biomass data, and there the difference was slight (an RMSE of 0.191 for Model 1 compared to an RMSE of 0.199 for Model 2). Model 2 tended to give better effective sample sizes for the size composition components (as would be expected given the addition of 28 parameters designed to do exactly that), and Model 2 had a higher AIC value than Model 1. On balance, therefore, the evidence supported selection of Model 2 as the final model.

Parameter Estimates Associated with the Final Model

The model estimated length-at-age parameter values of $K = 0.215$ and $L_2 = 93.9$. Estimates of fishing mortality rates $F_{g,y,i}$, recruitments R_y and initial numbers at age N_a, and selectivity parameters $S_{1\text{-}7,g,e(y|g)}$ are shown in Tables 2.18, 2.19, and 2.20, respectively. In addition, the parameter estimates listed in the section entitled "Parameters Estimated Independently" also pertain.

Schedules Defined by Final Parameter Estimates

Lengths at age defined by the final parameter estimates are shown below (lengths are in cm and are evaluated at the mid-point of each age group):

Age group:	1	2	3	4	5	6	7	8	9	10	11	12
Average length:	15	32	46	57	66	73	79	83	87	90	93	97

The distribution of lengths at age (measured in mid-year) defined by the final parameter estimates is shown in Table 2.22.

Weights at length and maturity proportions at length defined by the final parameters are shown in Table 2.23, and selectivities at length defined by the final parameter estimates are shown in Table 2.24.

RESULTS

Definitions

The biomass estimates presented here will be defined in three ways: 1) age 3+ biomass, consisting of the biomass of all fish aged three years or greater in January of a given year (vector *b* in Appendix 2A); 2) spawning biomass, consisting of the biomass of all spawning females in March of a given year (vector *c* in Appendix 2A); and 3) survey biomass, consisting of the biomass of all fish that the model estimates should have been observed by the survey in July of a given year (vector *d* in Appendix 2A). The recruitment estimates presented here will be defined in two ways: 1) as numbers of age 3 fish in January of a given year and 2) as the recruitment parameter R_y, which represents numbers at age 1 in January of year *y*. The fishing mortality rates presented here will be defined as full-selection, instantaneous fishing mortality rates expressed on a per annum scale.

Biomass

Model 2's estimate of the recent history of the stock (EBS portion only) is shown in Table 2.25, together with estimates provided in last year's final SAFE report (Thompson and Dorn 2001). The biomass trends estimated in the present assessment are also shown in Figure 2.9. The model's estimated time series of "survey" biomass parallels the biomass trend from the actual survey reasonably well, particularly given the occasional volatility of the survey time series. The model's estimate of survey biomass is within two standard deviations of the survey point estimate in 16 out of 24 years. Exceptions occur with respect to the 1982, 1985, 1991, and 1992 estimates, where the model's estimates are more than two standard deviations above the data, and with respect to the 1979, 1994, 1995, and 2001 estimates, where the model's estimates are more than two standard deviations below the data.

Figure 2.10 compares this year's (Model 2) estimate of the survey biomass time series with those from all other assessments since 1997 (the year in which the base model was standardized). These annual estimates have been remarkably consistent. If each assessment's estimate of the survey biomass time series had been used to predict the next assessment's estimate of the same time series, the R^2 would have ranged from a low of 0.989 (using the 2000 estimates to predict the 2001 estimates) to a high of 0.998 (using the 1998 estimates to predict the 1999 estimates) . There is no obvious time trend in the survey biomass estimates between assessments.

Model 2's estimated age 3+ biomass shows a near-continual decline since 1987, with upturns occurring only in 1995, 2000, and 2002. The model's estimated spawning biomass shows a continual decline from 1987 through 2000, with upturns occurring in 2001 and 2002. These recent upturns notwithstanding, Model 2's estimate of 2002 spawning biomass is the third lowest in the time series since 1981.

Figure 2.11 compares this year's (Model 2) estimate of the age 3+ biomass time series with those from all other assessments since 1997. Like the estimates of survey biomass, these annual estimates have been remarkably consistent. If each assessment's estimate of the age 3+ biomass time series had been used to predict the next assessment's estimate of the same time series, the R^2 would have ranged from a low of 0.942 (using the 1998 estimates to predict the 1999 estimates) to a high of 0.998 (using the 2000 estimates to predict the 2001 estimates). Unlike the annual estimates of the survey biomass time series, there appears to be a time trend in the age 3+ biomass estimates between assessments. To measure this trend, the relative change in each year's age 3+ biomass estimate as assessed between each pair of successive assessments was computed (e.g., the relative change in the estimated value of age 3+ biomass for 1985 as assessed in, say, the 2000 and 2001 assessments), then the relative changes were averaged for each pair of successive assessments. The average relative change between the 1997 and 1998 assessments was negative, but for all other pairs of successive assessments the average relative change was either zero or positive, as shown in the table below:

First assessment year	1997	1998	1999	2000	2001
Second assessment year	1998	1999	2000	2001	2002
Average relative change in age 3+ biomass	-0.033	0.075	0.070	0.000	0.006

Assuming that the assessments have become more accurate over time, the above table indicates that recent assessments have tended to err on the conservative side (i.e., they tend to underestimate age 3+ biomass).

Recruitment

Numbers at Age 3

Traditionally, recruitment strengths for Pacific cod have been assessed at age 3, because this is the approximate age of first significant recruitment to the fishery and because model estimates of relative year class strength tend to stabilize by this age. The model's estimated time series of age 3 recruitments is shown in Table 2.26, together with the estimates provided in last year's final SAFE report (Thompson and Dorn 2001). The model's recruitment estimates are also plotted in Figure 2.12. The current time series has a mean value of 241 million fish, a coefficient of variation of 60%, and an autocorrelation coefficient of -0.042.

One possible means of assigning a qualitative ranking to each year class within this time series is as follows: an "above average" year class can be defined as one in which numbers at age 3 are at least 120% of the mean, an "average" year class can be defined as one in which numbers at age 3 are less than 120% of the mean but at least 80% of the mean, and a "below average" year class can be defined as one in which numbers at age 3 are less than 80% of the mean. These criteria give the following classification of year class strengths:

Above average:	1977	1978	1979	1982	1984	1992							
Average:	1980	1985	1990	1989	1996	1999							
Below average:	1975	1976	1981	1983	1986	1987	1988	1991	1993	1994	1995	1997	1998

Except for the addition of the 1999 year class to the "above average" category and a reclassification of the 1989 year class from "above average" to "average," these results are identical to those presented in last year's SAFE report (Thompson and Dorn 2001). Last year's SAFE report noted that the 1989 year class was near the boundary between the "above average" and "average" categories.

Numbers at Age 1

The model's estimated time series of age 1 recruitments is shown in Table 2.19. This time series has a mean value of 526 million fish, a coefficient of variation of 58%, and an autocorrelation coefficient of -0.024. The qualitative rankings of year class strengths at age 1 naturally parallel the rankings at age 3, except that estimates for the 1975 and 1976 year classes do not exist at age 1 and the 2000 and 2001 year classes are added to the time series. The 2000 year class appears to be well above average, while the 2001 year class appears to be well below average. The model's estimate of age 1 recruitment from the 2000 year class is the fourth highest in the time series, although it should be noted that this estimate is based almost entirely on the 2001 and 2002 survey size composition data.

The present assessment model is not configured to estimate a stock-recruitment relationship. Estimation of stock-recruitment relationships is a notoriously difficult exercise in the field of stock assessment, because both the stock data and the recruitment data are measured with error and because the errors in the stock-recruitment data are autocorrelated (Walters and Ludwig 1981). Also, if the stock and recruitment data are generated by a model which assumes that no stock-recruitment relationship exists, these data will be biased. Nevertheless, the stock-recruitment relationship is potentially such an important component of stock dynamics that it seems prudent to provide some kind of investigation, albeit provisional, as to its possible shape. In addition, the SSC has requested that the assessment include a stock-recruitment relationship (SSC minutes, December, 2000 and December, 2001). To this end, the following analysis was conducted (use of symbols in this description does not necessarily follow Table

2.14, which pertains to the Synthesis assessment model only):

1) Age 1 recruitment R in year y+1 was assumed to be related to spawning biomass S in year y by the Ricker (1954) stock-recruitment relationship subject to lognormal error:

$$R_{y+1} = S_y \exp\left(-\alpha - \beta S_y + \varepsilon_y\right),$$

where α and β are parameters and the ε_y are drawn from a normal distribution with mean 0 and variance σ^2.
2) The estimates of spawning biomass generated by Synthesis were treated as known constants (i.e., it was assumed that they are measured without error).
3) Parameters were estimated by the method of maximum likelihood.
4) The covariance of the parameter estimates was assumed to equal the inverse of the Hessian matrix.

The point estimates of the parameters were α = -1.701, β = 0.003342, and σ = 0.600. The 95% confidence interval of the stock-recruitment parameters is shown in the upper panel of Figure 2.13. One of the attractive features of the method described above is that it implies that the stock-recruitment relationship $r(S) = S\exp(-\alpha-\beta S)$ is itself a lognormal random variable with parameters that are functions of stock size. The coefficient of variation for the relationship is minimized at the mean of the stock data. The lower panel of Figure 2.13 shows the data (solid squares), the stock-recruitment relationship defined by the point estimates of the parameters (thick curve), and the 95% confidence interval around the stock-recruitment relationship (thin curves). This analysis is useful mostly because it indicates a considerable level of uncertainty regarding the shape of the stock-recruitment relationship. Moreover, this description of uncertainty should be regarded as an underestimate because of the problems noted in the paragraph above. The estimates given here are not recommended for use in estimating maximum sustainable yield.

Exploitation

The model's estimated time series of the ratio between EBS catch and age 3+ biomass is shown in Table 2.27, together with the estimates provided in last year's final SAFE report (Thompson and Dorn 2001). The average value of this ratio over the entire time series is about 0.088. The estimated values exceed the average for every year after 1990 except 1993, whereas none of the estimated values exceed the average in any year prior to 1991 except 1978.

PROJECTIONS AND HARVEST ALTERNATIVES

Amendment 56 Reference Points

Amendment 56 to the BSAI Groundfish Fishery Management Plan (FMP) defines the "overfishing level" (OFL), the fishing mortality rate used to set OFL (F_{OFL}), the maximum permissible ABC, and the fishing mortality rate used to set the maximum permissible ABC. The fishing mortality rate used to set ABC (F_{ABC}) may be less than this maximum permissible level, but not greater. Because reliable estimates of reference points related to maximum sustainable yield (MSY) are currently not available but reliable estimates of reference points related to spawning per recruit are available, Pacific cod in the BSAI are managed under Tier 3 of Amendment 56. Tier 3 uses the following reference points: $B_{40\%}$, equal to 40% of the equilibrium spawning biomass that would be obtained in the absence of fishing; $F_{35\%}$, equal to the fishing mortality rate that reduces the equilibrium level of spawning per recruit to 35% of the level that would be obtained in the absence of fishing; and $F_{40\%}$, equal to the fishing mortality rate that reduces the equilibrium level of spawning per recruit to 40% of the level that would be obtained in the absence of fishing. The following formulae apply under Tier 3:

3a) *Stock status:* $B/B_{40\%} > 1$
$F_{OFL} = F_{35\%}$
$F_{ABC} \leq F_{40\%}$
3b) *Stock status:* $1/20 < B/B_{40\%} \leq 1$
$F_{OFL} = F_{35\%} \times (B/B_{40\%} - 1/20) \times 20/19$
$F_{ABC} \leq F_{40\%} \times (B/B_{40\%} - 1/20) \times 20/19$
3c) *Stock status:* $B/B_{40\%} \leq 1/20$
$F_{OFL} = 0$
$F_{ABC} = 0$

Estimation of the $B_{40\%}$ reference point used in the above formulae requires an assumption regarding the equilibrium level of recruitment. In this assessment, it is assumed that the equilibrium level of recruitment is equal to the post-1976 average (i.e., the arithmetic mean of all estimated recruitments from year classes spawned in 1977 or later). Other useful biomass reference points which can be calculated using this assumption are $B_{100\%}$ and $B_{35\%}$, defined analogously to $B_{40\%}$. These reference points are estimated as follows:

Reference point:	$B_{35\%}$	$B_{40\%}$	$B_{100\%}$
EBS:	322,000 t	368,000 t	923,000 t
BSAI:	377,000 t	431,000 t	1,080,000 t

(For purposes of comparison, Model 1 estimates BSAI $B_{35\%}$ and $B_{40\%}$ at values of 376,000 t and 430,000 t, respectively.)

For a stock exploited by multiple gear types, estimation of $F_{35\%}$ and $F_{40\%}$ requires an assumption regarding the apportionment of fishing mortality among those gear types. Current regulations specify that catches of Pacific cod will be allocated according to gear type as follows: the trawl fishery will be allocated 47%, the fixed gear (longline and pot) fishery will be allocated 51%, and the jig fishery will be allocated 2%; of the fixed gear allocation, the longline fishery will be allocated 80.3% (not counting catcher vessels less than 60 ft LOA), the pot fishery will be allocated 18.3% (not counting catcher vessels less than 60 ft. LOA), and fixed-gear catcher vessels less than 60 ft. LOA will be allocated 1.4%. This allocation formula was then integrated into calculation of reference points in this assessment as follows: First, to simplify the analysis, it was assumed that the 1.4% of the fixed-gear allocation that is reserved for catcher vessels less than 60 ft. LOA would be taken in the longline fishery. Second, since available data are insufficient to estimate selectivities for the jig fishery, the jig fishery was merged into the other commercial fisheries. Third, total fishing mortality was apportioned between gear types (early trawl, late trawl, longline, and pot) at a ratio of 441:57:389:113. These proportions result in a 2003 catch composition that matches both the 47:51 trawl:fixed allocation, the 817:183 longline:pot allocation and the recent (1999-2001) average distribution of catches between the early and late trawl fisheries. It should be noted that this apportionment scheme is generally consistent with existing Steller sea lion protection measures. This apportionment results in the following estimates of $F_{35\%}$ and $F_{40\%}$:

$F_{35\%}$	$F_{40\%}$
0.42	0.35

(For purposes of comparison, Model 1estimates $F_{35\%}$ and $F_{40\%}$ at values of 0.41 and 0.34, respectively.)

Specification of OFL and Maximum Permissible ABC

BSAI spawning biomass for 2003 is estimated at a value of 423,000 t (EBS value = 362,000 t). This is about 2% below the BSAI $B_{40\%}$ value of 431,000 t (EBS value = 368,000 t), thereby placing Pacific cod in sub-tier "b" of Tier 3. Given this, the model estimates OFL, maximum permissible ABC, and the associated fishing mortality rates for 2003 as follows:

	Overfishing Level	Maximum Permissible ABC
EBS catch:	277,000 t	238,000 t
BSAI catch:	324,000 t	278,000 t
Fishing mortality rate:	0.41	0.35

The age 3+ biomass estimates for 2003 are 1,680,000 t and 1,440,000 t for the BSAI and EBS, respectively. (For purposes of comparison, Model 1 estimates the BSAI OFL for 2003 at a value of 322,000 t, the maximum permissible BSAI ABC for 2003 at a value of 276,000 t, the F_{OFL} at a value of 0.40, the maximum permissible F_{ABC} at a value of 0.34, and the BSAI age 3+ biomass for 2003 at a value of 1,680,000 t.)

ABC Recommendation

It is important to remember that the maximum permissible ABC computed under the stock assessment model is only a point estimate, around which there is significant uncertainty. For the past several years, the BSAI and GOA Pacific cod assessments have advocated a harvest strategy that formally addresses some of this uncertainty, namely the uncertainty surrounding parameters M and Q (see "Model Structure" above). For the assessments conducted in 2000 and 2001, the strategy was simplified by assuming that the ratio between the recommended F_{ABC} and $F_{40\%}$ estimate given in the 1999 assessment (0.87) was an appropriate factor by which to multiply the current maximum permissible F_{ABC} to obtain a recommended F_{ABC}. The same strategy is recommended for setting the 2003 ABC. This strategy results in a recommended 2003 BSAI ABC of 245,000 t (EBS value = 209,000 t), corresponding to a fishing mortality rate of 0.30. (For purposes of comparison, Model 1 results in a recommended 2003 BSAI ABC of 244,000 t, corresponding to a fishing mortality rate of 0.30.)

Standard Harvest and Recruitment Scenarios and Projection Methodology

A standard set of projections is required for each stock managed under Tiers 1, 2, or 3 of Amendment 56. This set of projections encompasses seven harvest scenarios designed to satisfy the requirements of Amendment 56, the National Environmental Policy Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA).

For each scenario, the projections begin with the vector of 2002 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2003 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2002. In each subsequent year, the fishing mortality rate is prescribed on the basis of the spawning biomass in that year and the respective harvest scenario. In each year, recruitment is drawn from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined from recruitments estimated in the assessment. Spawning biomass is computed in each year based on the time of peak spawning and the maturity and weight schedules described in the assessment. Total catch is assumed to equal the catch associated with the respective harvest scenario in all years. This projection scheme is run 1000 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

Five of the seven standard scenarios will be used in an Environmental Assessment prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2003, are as follow ("*max* F_{ABC}" refers to the maximum permissible value of F_{ABC} under Amendment 56):

Scenario 1: In all future years, F is set equal to *max* F_{ABC}. (Rationale: Historically, TAC has been constrained by ABC, so this scenario provides a likely upper limit on future TACs.)

Scenario 2: In all future years, F is set equal to a constant fraction of *max* F_{ABC}, where this fraction is equal to the ratio of the F_{ABC} value for 2003 recommended in the assessment to the *max* F_{ABC} for 2003. (Rationale: When F_{ABC} is set at a value below *max* F_{ABC}, it is often set at the value recommended in the stock assessment.)

Scenario 3: In all future years, F is set equal to 50% of *max* F_{ABC}. (Rationale: This scenario provides a likely lower bound on F_{ABC} that still allows future harvest rates to be adjusted downward when stocks fall below reference levels.)

Scenario 4: In all future years, F is set equal to the 1997-2001 average F, which was 0.20. (Rationale: For some stocks, TAC can be well below ABC, and recent average F may provide a better indicator of F_{TAC} than F_{ABC}.)

Scenario 5: In all future years, F is set equal to zero. (Rationale: In extreme cases, TAC may be set at a level close to zero.)

Two other scenarios are needed to satisfy the MSFCMA's requirement to determine whether a stock is currently in an overfished condition or is approaching an overfished condition. These two scenarios are as follow (for Tier 3 stocks, the MSY level is defined as $B_{35\%}$):

Scenario 6: In all future years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is overfished. If the stock is expected to be 1) above its MSY level in 2003 or 2) above ½ of its MSY level in 2003 and above its MSY level in 2013 under this scenario, then the stock is not overfished.)

Scenario 7: In 2003 and 2004, F is set equal to *max* F_{ABC}, and in all subsequent years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is expected to be above its MSY level in 2015 under this scenario, then the stock is not approaching an overfished condition.)

Projections and Status Determination

Table 2.28 defines symbols used to describe projections of spawning biomass, fishing mortality rate, and catch corresponding to the seven standard harvest scenarios. These projections are shown in Tables 2.29-35.

Harvest scenarios #6 and #7 are intended to permit determination of the status of a stock with respect to its minimum stock size threshold (MSST). Any stock that is below its MSST is defined to be *overfished*. Any stock that is expected to fall below its MSST in the next two years is defined to be *approaching* an overfished condition. Harvest scenarios #6 and #7 are used in these determinations as follows:

Is the stock overfished? This depends on the stock's estimated spawning biomass in 2003:

a) If spawning biomass for 2003 is estimated to be below ½ $B_{35\%}$, the stock is below its MSST.
b) If spawning biomass for 2003 is estimated to be above $B_{35\%}$, the stock is above its MSST.
c) If spawning biomass for 2003 is estimated to be above ½ $B_{35\%}$ but below $B_{35\%}$, the stock's status relative to MSST is determined by referring to harvest scenario #6 (Table 2.34). If the mean spawning biomass for 2013 is below $B_{35\%}$, the stock is below its MSST. Otherwise, the stock is above its MSST.

Is the stock approaching an overfished condition? This is determined by referring to harvest scenario #7 (Table 2.35):

a) If the mean spawning biomass for 2005 is below ½ $B_{35\%}$, the stock is approaching an overfished condition.
b) If the mean spawning biomass for 2005 is above $B_{35\%}$, the stock is not approaching an overfished condition.
c) If the mean spawning biomass for 2005 is above ½ $B_{35\%}$ but below $B_{35\%}$, the determination depends on the mean spawning biomass for 2015. If the mean spawning biomass for 2015 is below $B_{35\%}$, the stock is approaching an overfished condition. Otherwise, the stock is not approaching an overfished condition.

In the case of BSAI Pacific cod, spawning biomass for 2003 is estimated to be above $B_{35\%}$. Therefore, the stock is above its MSST and is not overfished. Mean spawning biomass for 2005 in Table 2.35 is above $B_{35\%}$. Therefore, the stock is not approaching an overfished condition.

OTHER CONSIDERATIONS

Ecosystem Effects on the Stock

A primary ecosystem phenomenon affecting the BSAI Pacific cod stock seems to be the occurrence of periodic "regime shifts," in which central tendencies of key variables in the physical environment change on a scale spanning several years to a few decades (Livingston, ed., 2002). One well-documented example of such a regime shift occurred in 1977, and shifts occurring in 1989 and 1999 have also been suggested (e.g., Hare and Mantua 2000). However, if regime shifts did occur in 1989 or 1999, it is not yet clear that they had any impact on Pacific cod.

The prey and predators of Pacific cod have been described or reviewed by Albers and Anderson (1985), Livingston (1989, 1991), and Westrheim (1996). In terms of percent occurrence, the most important items in the diet of Pacific cod in the BSAI and GOA are polychaetes, amphipods, and crangonid shrimp. In terms of numbers of individual organisms consumed, the most important dietary items are euphausids, miscellaneous fishes, and amphipods. In terms of weight of organisms consumed, the most important dietary items are walleye pollock, fishery offal, and yellowfin sole. Small Pacific cod feed mostly on invertebrates, while large Pacific cod are mainly piscivorous. Predators of Pacific cod include halibut, salmon shark, northern fur seals, Steller sea lions, harbor porpoises, various whale species, and tufted puffin. Major trends in the most important prey or predator species could be expected to affect the dynamics of Pacific cod to some extent.

Fishery Effects on the Ecosystem

Potentially, fisheries for Pacific cod can have effects on other species in the ecosystem through a variety of mechanisms, for example by relieving predation pressure on shared prey species (i.e., species which serve as prey for both Pacific cod and other species), by reducing prey availability for predators of Pacific cod, by altering habitat, by imposing bycatch mortality, or by "ghost fishing" caused by lost fishing gear.

Steller Sea Lions

Sinclair and Zeppelin (2002) showed that Pacific cod was one of the four most important prey items of Steller sea lions in terms of frequency of occurrence averaged over years, seasons, and sites, and was especially important in winter. Pitcher (1981) and Calkins (1998) also showed Pacific cod to be an important winter prey item in the GOA and BSAI, respectively. Furthermore, the size ranges of Pacific cod harvested by the fisheries and consumed by Steller sea lions overlap, and the fishery operates to some extent in the same geographic areas used by Steller sea lion as foraging grounds (Livingston, ed., 2002).

Seabirds

The following is a summary of information provided by Livingston (ed., 2002): In both the BSAI and GOA, the northern fulmar (*Fulmarus glacialis*) comprises the majority of seabird bycatch, which occurs primarily in the longline fisheries, including the longline fishery for Pacific cod. Shearwater (*Puffinus* spp.) distribution overlaps with the Pacific cod longline fishery in the Bering Sea, and with trawl fisheries in general in both the Bering Sea and GOA. Black-footed albatross (*Phoebastria nigripes*) is taken in much greater numbers in the GOA longline fisheries than the Bering Sea longline fisheries, but is not taken in the trawl fisheries. The distribution of Laysan albatross (*Phoebastria immutabilis*) appears to overlap with the longline fisheries in the central and western Aleutians. The distribution of short-tailed albatross (*Phoebastria albatrus*) also overlaps with the Pacific cod longline fishery along the Aleutian chain, although the majority of the bycatch has taken place along the northern portion of the Bering Sea shelf edge (in contrast, only two takes have been recorded in the GOA). Some success has been obtained in devising measures to mitigate fishery-seabird interactions. For example, on vessels larger than 60 ft. LOA, paired streamer lines of specified performance and material standards have been found to reduce seabird incidental take significantly.

Fishery Usage of Habitat

The following is a summary of information provided by Livingston (ed., 2002): The longline and trawl fisheries for Pacific cod each comprise an important component of the combined fisheries associated with the respective gear type in each of the three major management regions (BS, AI, and GOA). Looking at each gear type in each region as a whole (i.e., aggregating across all target species) during the period 1998-2001, the total number of observed sets was as follows:

Gear	BS	AI	GOA
Trawl	240,347	43,585	68,436
Longline	65,286	13,462	7,139

In the BS, both longline and trawl effort was concentrated north of False Pass (Unimak Island) and along the shelf edge represented by the boundary of areas 513, 517 (in addition, longline effort was concentrated along the shelf edge represented by the boundary of areas 521-533). In the AI, both longline and trawl effort was dispersed over a wide area along the shelf edge. The catcher vessel longline fishery in the AI occurred primarily over mud bottoms. Longline catcher-processors in the AI tended to fish more over rocky bottoms. In the GOA, fishing effort was also dispersed over a wide area along the shelf, though pockets of trawl effort were located near Chirikof, Cape Barnabus, Cape Chiniak and Marmot Flats. The GOA longline fishery for Pacific cod generally took place over gravel, cobble, mud, sand, and rocky bottoms, in depths of 25 fathoms to 140 fathoms.

SUMMARY

The major results of the Pacific cod stock assessment are summarized in Table 2.36.

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Table 2.1--Summary of catches (t) of Pacific cod by management area, fleet sector, and gear type (page 1 of 3). All catches since 1980 include discards. LLine = longline, Subt. = sector subtotal. Catches for 2002 are through August. Catches by gear are not available prior to 1981.

Eastern Bering Sea Only:

Year	Foreign			Joint Venture		Domestic Annual Processing					Total
	Trawl	LLine	Subt.	Trawl	Subt.	Trawl	LLine	Pot	Other	Subt.	
1978			42512		0					31	42543
1979			32981		0					780	33761
1980			35058		8370					2433	45861
1981	30347	5851	36198	7410	7410	12884	1	0	14	12899	56507
1982	23037	3142	26179	9312	9312	23893	5	0	1715	25613	61104
1983	32790	6445	39235	9662	9662	45310	4	21	569	45904	94801
1984	30592	26642	57234	24382	24382	43274	8	0	205	43487	125103
1985	19596	36742	56338	35634	35634	51425	50	0	0	51475	143447
1986	13292	26563	39855	57827	57827	37646	48	62	167	37923	135605
1987	7718	47028	54746	47722	47722	46039	1395	1	0	47435	149903
1988	0	0	0	106592	106592	93706	2474	299	0	96479	203071
1989	0	0	0	44612	44612	119631	13935	145	0	133711	178323
1990	0	0	0	8078	8078	115493	47114	1382	0	163989	172067
1991	0	0	0	0	0	129392	76734	3343	0	209469	209469
1992	0	0	0	0	0	77259	80168	7512	33	164972	164972
1993	0	0	0	0	0	81762	49293	2098	2	133155	133155
1994	0	0	0	0	0	84931	78563	8037	730	172261	172261
1995	0	0	0	0	0	110956	97665	19275	599	228496	228496
1996	0	0	0	0	0	91910	88882	28006	267	209064	209064
1997	0	0	0	0	0	93924	117008	21493	173	232598	232598
1998	0	0	0	0	0	61145	86140	13207	192	160684	160684
1999	0	0	0	0	0	51902	81463	12399	100	145865	145865
2000	0	0	0	0	0	53815	81640	15849	68	151372	151372
2001	0	0	0	0	0	35655	90360	16385	52	142452	142452
2002	0	0	0	0	0	46060	62124	11099	163	119447	119447

Table 2.1--Summary of catches (t) of Pacific cod by management area, fleet sector, and gear type (page 2 of 3). All catches since 1980 include discards. LLine = longline, Subt. = sector subtotal. Catches for 2002 are through August. Catches by gear are not available prior to 1981.

Aleutian Islands Region Only:

Year	Foreign			Joint Venture		Domestic Annual Processing					Total
	Trawl	LLine	Subt.	Trawl	Subt.	Trawl	LLine	Pot	Other	Subt.	
1978			0		0					0	0
1979			0		0					0	0
1980			0		86					0	86
1981	2680	235	2915	1749	1749	2744	26	0	0	2770	7434
1982	1520	476	1996	4280	4280	2121	0	0	0	2121	8397
1983	1869	402	2271	4700	4700	1459	0	0	0	1459	8430
1984	473	804	1277	6390	6390	314	0	0	0	314	7981
1985	10	829	839	5638	5638	460	0	0	0	460	6937
1986	5	0	5	6115	6115	784	1	1	0	786	6906
1987	0	0	0	10435	10435	2662	22	88	0	2772	13207
1988	0	0	0	3300	3300	1698	137	30	0	1865	5165
1989	0	0	0	6	6	4233	284	19	0	4536	4542
1990	0	0	0	0	0	6932	602	7	0	7541	7541
1991	0	0	0	0	0	3414	3203	3180	0	9797	9797
1992	0	0	0	0	0	14558	22108	6317	84	43068	43068
1993	0	0	0	0	0	17312	17693	0	33	35037	35037
1994	0	0	0	0	0	14382	7009	147	0	21539	21539
1995	0	0	0	0	0	10574	4935	1024	0	16534	16534
1996	0	0	0	0	0	21179	5819	4611	0	31609	31609
1997	0	0	0	0	0	17349	7151	575	89	25164	25164
1998	0	0	0	0	0	20757	13782	425	0	34964	34964
1999	0	0	0	0	0	16437	7874	3750	69	28130	28130
2000	0	0	0	0	0	0	16183	20362	3139	39684	39684
2001	0	0	0	0	0	15826	17817	544	19	34207	34207
2002	0	0	0	0	0	0	2558	27444	6	30009	30009

Table 2.1--Summary of catches (t) of Pacific cod by management area, fleet sector, and gear type (page 3 of 3). All catches since 1980 include discards. LLine = longline, Subt. = sector subtotal. Catches for 2002 are through August. Catches by gear are not available prior to 1981.

Eastern Bering Sea and Aleutian Islands Region Combined:

Year	Foreign			Joint Venture		Domestic Annual Processing					Total
	Trawl	LLine	Subt.	Trawl	Subt.	Trawl	LLine	Pot	Other	Subt.	
1978			42512		0					31	42543
1979			32981		0					780	33761
1980			35058		8456					2433	45947
1981	33027	6086	39113	9159	9159	15628	27	0	14	15669	63941
1982	24557	3618	28175	13592	13592	26014	5	0	1715	27734	69501
1983	34659	6847	41506	14362	14362	46769	4	21	569	47363	103231
1984	31065	27446	58511	30772	30772	43588	8	0	205	43801	133084
1985	19606	37571	57177	41272	41272	51885	50	0	0	51935	150384
1986	13297	26563	39860	63942	63942	38430	49	63	167	38709	142511
1987	7718	47028	54746	58157	58157	48701	1417	89	0	50207	163110
1988	0	0	0	109892	109892	95404	2611	329	0	98344	208236
1989	0	0	0	44618	44618	123864	14219	164	0	138247	182865
1990	0	0	0	8078	8078	122425	47716	1389	0	171530	179608
1991	0	0	0	0	0	132806	79937	6523	0	219266	219266
1992	0	0	0	0	0	91818	102276	13829	117	208039	208039
1993	0	0	0	0	0	99074	66986	2098	35	168192	168192
1994	0	0	0	0	0	99313	85573	8184	730	193800	193800
1995	0	0	0	0	0	121530	102600	20299	599	245029	245029
1996	0	0	0	0	0	113089	94701	32617	267	240673	240673
1997	0	0	0	0	0	111273	124159	22068	262	257762	257762
1998	0	0	0	0	0	81903	99921	13632	192	195648	195648
1999	0	0	0	0	0	68339	89337	16150	169	173995	173995
2000	0	0	0	0	0	53815	97823	36210	3207	191056	191056
2001	0	0	0	0	0	51482	108177	16929	71	176659	176659
2002	0	0	0	0	0	46060	64683	38544	169	149456	149456

Table 2.2--History of Pacific cod ABC, TAC, total BSAI catch, and type of stock assessment model used to recommend ABC. Catch for 2002 is current through August.

Year	ABC	TAC	Catch	Stock Assessment Model
1980	148,000	70,700	45,947	projection of 1979 survey numbers at age
1981	160,000	78,700	63,941	projection of 1979 survey numbers at age
1982	168,000	78,700	69,501	projection of 1979 survey numbers at age
1983	298,200	120,000	103,231	projection of 1979 survey numbers at age
1984	291,300	210,000	133,084	projection of 1979 survey numbers at age
1985	347,400	220,000	150,384	projection of 1979-1985 survey numbers at age
1986	249,300	229,000	142,511	separable age-structured model
1987	400,000	280,000	163,110	separable age-structured model
1988	385,300	200,000	208,236	separable age-structured model
1989	370,600	230,681	182,865	separable age-structured model
1990	417,000	227,000	179,608	separable age-structured model
1991	229,000	229,000	219,266	separable age-structured model
1992	182,000	182,000	208,039	age-structured Synthesis model
1993	164,500	164,500	168,192	length-structured Synthesis model
1994	191,000	191,000	193,800	length-structured Synthesis model
1995	328,000	250,000	245,029	length-structured Synthesis model
1996	305,000	270,000	240,673	length-structured Synthesis model
1997	306,000	270,000	257,762	length-structured Synthesis model
1998	210,000	210,000	195,648	length-structured Synthesis model
1999	177,000	177,000	173,995	length-structured Synthesis model
2000	193,000	193,000	191,056	length-structured Synthesis model
2001	188,000	188,000	176,659	length-structured Synthesis model
2002	223,000	200,000	149,456	length-structured Synthesis model

Table 2.3–Total catch and discards of Pacific cod in the 2001 and 2002 fisheries. Data for 2002 are through October 5. "Catcher-Proc."="CP"=catcher-processor, "Catch"=total catch (t), "Disc."=discards (t), "Rate"=ratio of discards to total catch, "CV"=catcher vessel, "HAL"=longline.

		Shoreside		Mothership		Catcher-Proc.		All		
Year	Fleet	Catch	Disc.	Catch	Disc.	Catch	Disc.	Catch	Disc.	Rate
2001	Trawl CP	0	0	0	0	29,398	867	29,398	867	0.029
2001	Trawl CV	16,746	53	4,608	153	0	0	21,354	206	0.010
2001	HAL CP	0	0	0	0	96,237	1,527	96,237	1,527	0.016
2001	HAL CV	637	25	0	0	0	0	637	25	0.039
2001	Pot	12,036	27	1,364	0	3,107	25	16,507	52	0.003
2001	Jig	71	0	0	0	0	0	71	0	0.000
2001	Total	29,490	105	5,972	153	128,742	2,419	164,204	2,677	0.016

		Shoreside		Mothership		Catcher-Proc.		All		
Year	Fleet	Catch	Disc.	Catch	Disc.	Catch	Disc.	Catch	Disc.	Rate
2002	Trawl CP	0	0	0	0	35,463	1,213	35,463	1,213	0.034
2002	Trawl CV	31,733	321	8,971	242	0	0	40,704	563	0.014
2002	HAL CP	0	0	0	0	69,670	1,381	69,670	1,381	0.020
2002	HAL CV	396	164	0	0	0	0	396	164	0.414
2002	Pot	10,607	35	1,478	0	1,643	0	13,728	35	0.003
2002	Jig	164	0	0	0	0	0	164	0	0.000
2002	Total	42,900	520	10,449	242	106,776	2,594	160,125	3,356	0.021

Table 2.4--Catch (t) of Pacific cod by year, gear, and period. Catch for 2002 is complete through period 2 (August). Distribution of catch for 1978-1980 by gear and period was estimated from other years' data.

Year	Trawl			Longline			Pot		
	Period 1	Period 2	Period 3	Period 1	Period 2	Period 3	Period 1	Period 2	Period 3
1978	10424	11288	18021	1371	1032	1856	0	0	0
1979	10397	12587	10403	1371	699	547	0	0	0
1980	9452	9007	17039	1106	206	4230	0	0	0
1981	15067	14087	21486	1286	624	3942	0	0	0
1982	21742	18151	16348	363	475	2308	0	0	0
1983	40757	24300	22705	2941	748	2756	0	0	0
1984	48237	24964	25045	5012	2128	19508	0	0	0
1985	55673	28673	22310	13703	1710	21379	0	0	0
1986	59786	26598	22382	8895	438	17278	0	0	0
1987	64413	15604	21462	20947	723	26752	0	0	0
1988	127470	25662	47166	444	646	1385	90	51	160
1989	127459	16986	19798	3810	4968	5157	33	63	49
1990	101645	11402	10524	13171	16643	17299	0	986	395
1991	107979	15549	5863	25470	21472	29792	12	1042	2288
1992	59460	11840	5959	49696	24195	6276	2622	4632	258
1993	67120	5362	9280	49242	27	23	2073	24	0
1994	61009	5806	18115	57968	13	20582	4923	0	3113
1995	90366	8543	12047	68458	26	29180	12484	3469	3322
1996	78194	3126	10590	62011	26	26845	18143	6401	3462
1997	81313	3927	8684	70676	43	46290	14584	3576	3333
1998	45130	5629	10386	54219	27	31893	9022	2779	1407
1999	44904	3312	3686	55180	1923	24360	9346	1001	2052
2000	44508	4578	4730	40180	1375	40086	15742	0	107
2001	22849	7025	5781	38368	6700	45291	11646	494	4298
2002	36572	9488	0	50023	12101	0	10746	516	0

Table 2.5--Pacific cod length sample sizes from the commercial fisheries.

Year	Trawl Fishery			Longline Fishery			Pot Fishery		
	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3
1978	646	0	3161	2885	4886	2514	0	0	0
1979	1667	0	748	11410	2514	2662	0	0	0
1980	1359	73	327	2600	1389	2932	0	0	0
1981	132	0	1540	2253	1276	1300	0	0	0
1982	592	226	1643	2910	1203	5078	0	0	0
1983	12386	1231	14577	18800	4119	9610	0	0	0
1984	10246	4482	4477	6853	6004	82103	0	0	0
1985	30171	1556	3051	0	4561	134469	0	0	0
1986	28566	1813	2548	18588	200	104142	0	0	0
1987	46360	6674	20923	70273	0	165124	0	0	0
1988	103453	0	2897	0	0	0	0	0	0
1989	58575	612	669	0	0	0	0	0	0
1990	64143	9807	250	18900	74534	62550	0	1506	5772
1991	88727	2083	0	54671	70808	91693	0	10701	11243
1992	79286	0	0	152152	134263	20129	17289	48569	5147
1993	81637	0	0	154337	0	0	10557	0	0
1994	103839	0	0	172585	0	45350	25950	0	6436
1995	68575	0	0	144739	392	74766	47660	16786	13741
1996	104295	1139	3473	164051	156	75385	76393	23063	11199
1997	106847	275	0	184741	109	144489	43859	11760	11760
1998	108187	2790	2974	162821	62	190555	26595	8899	4522
1999	44845	228	1136	84227	10095	51065	22634	1875	8922
2000	47085	304	67	71413	9960	97697	26040	0	512
2001	26124	2787	1304	84559	27431	102235	15985	447	8447
2002	36744	1692	0	70459	11662	0	10967	312	0

Table 2.6–Length frequencies of Pacific cod in the pre-1989 trawl fishery by year, period, and length bin.

Yr.	Per	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1978	1	0	0	0	1	1	1	1	2	5	22	29	88	233	112	44	32	36	15	11	9	1	1	2	0	0
1978	3	0	0	0	0	0	6	35	79	37	21	19	5	62	387	999	882	337	159	81	37	13	2	0	0	0
1979	1	0	0	0	0	0	2	1	21	46	94	206	319	346	100	149	161	152	48	11	4	5	1	1	0	0
1979	3	0	0	0	0	0	0	0	3	5	24	74	150	220	78	38	47	58	31	14	4	0	0	0	1	1
1980	1	0	0	0	0	0	0	1	10	34	84	186	295	462	192	49	19	14	8	3	1	1	0	0	0	0
1980	2	0	0	0	0	0	0	0	0	0	0	0	0	1	16	45	8	3	0	0	0	0	0	0	0	0
1980	3	0	0	0	0	0	0	0	1	0	0	9	17	37	79	70	55	32	8	9	6	3	0	1	0	0
1981	1	0	0	0	0	0	0	0	0	0	0	0	8	28	43	34	16	3	0	0	0	0	0	0	0	0
1981	3	0	0	0	0	0	0	0	2	1	0	3	8	26	122	336	373	301	194	120	32	13	7	2	0	0
1982	1	0	0	0	0	0	1	1	4	21	22	9	13	48	61	94	133	84	69	20	8	3	1	0	0	0
1982	2	0	0	0	0	0	0	0	0	0	1	1	7	21	14	21	41	43	33	16	13	4	6	4	1	0
1982	3	0	0	0	0	0	0	1	0	0	1	4	27	70	143	215	196	302	346	215	90	18	9	5	1	0
1983	1	0	0	0	0	0	5	20	99	286	284	275	467	1113	1272	1978	2477	1982	1193	584	202	72	35	22	13	7
1983	2	0	0	0	0	0	1	0	1	3	10	4	7	31	95	204	289	249	187	85	30	11	8	6	7	3
1983	3	0	0	0	0	1	15	24	26	15	8	35	205	421	508	1451	1999	2487	2441	2235	1563	767	284	66	21	5
1984	1	0	1	1	1	0	7	121	251	222	132	66	148	439	503	758	1394	2027	1873	1278	639	263	96	16	9	1
1984	2	0	1	0	0	5	18	14	5	10	55	93	118	241	284	403	612	638	620	481	411	313	110	42	7	1
1984	3	0	0	0	0	0	7	21	15	114	434	370	188	137	124	254	396	576	614	483	376	224	99	32	13	0
1985	1	0	0	2	0	4	0	2	39	116	262	733	1768	2246	1088	1415	2474	5067	5635	4340	2649	1402	608	229	69	23
1985	2	0	0	0	0	0	0	0	3	24	77	70	119	425	356	116	59	70	88	73	35	20	8	9	3	1
1985	3	0	0	0	0	0	0	0	1	0	9	79	170	533	322	195	126	288	424	374	296	152	78	4	0	0
1986	1	0	4	16	8	34	62	118	249	636	761	683	788	2229	3564	3293	2108	2647	3498	3377	2446	1346	456	168	58	17
1986	2	0	0	0	0	0	0	7	4	2	4	5	9	26	95	130	195	285	481	352	128	48	30	8	4	0
1986	3	0	0	1	0	0	0	2	1	15	17	28	26	86	169	288	405	520	406	265	136	93	59	22	4	5
1987	1	0	0	3	13	15	58	194	446	516	640	1250	2235	4300	3164	3663	6190	6238	5028	4338	3669	2326	1255	510	234	75
1987	2	0	0	0	0	1	1	2	5	9	6	10	29	135	241	422	837	1294	1344	889	574	397	252	133	68	25
1987	3	0	0	0	0	0	0	0	0	7	13	68	76	263	1095	1809	2177	2736	3204	2732	2087	1946	1549	802	306	53
1988	1	1	0	1	1	6	30	93	605	1533	2081	2311	4634	11994	11361	10890	9690	10862	13124	11333	6319	3330	1855	913	380	106
1988	3	0	0	0	0	0	0	0	0	5	0	13	52	257	326	284	348	348	373	332	305	166	56	20	6	6

Table 2.7–Length frequencies of Pacific cod in the pre-1989 longline fishery by year, period, and length bin.

		Length Bin																								
Yr.	Per	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1978	1	0	0	0	0	0	0	0	0	1	4	23	124	623	812	435	269	216	160	110	58	36	7	7	0	0
1978	2	0	0	0	0	0	0	0	0	0	1	7	40	240	574	1226	994	716	566	330	133	44	12	2	1	0
1978	3	0	0	0	0	0	0	0	0	0	0	2	0	62	366	736	788	306	124	66	35	19	8	2	0	0
1979	1	0	0	0	0	0	0	0	8	83	377	683	436	375	1303	2454	2711	1575	679	380	208	87	36	8	7	0
1979	2	0	0	0	0	0	0	0	0	2	14	49	90	155	102	327	646	660	315	86	43	17	5	3	0	0
1979	3	0	0	0	0	0	0	0	0	0	2	10	47	233	249	174	387	683	599	216	41	10	9	2	0	0
1980	1	0	0	0	0	0	0	0	0	5	15	66	212	591	604	320	182	199	244	111	36	11	4	0	0	0
1980	2	0	0	0	0	0	0	0	0	0	0	1	29	169	334	293	185	148	140	67	17	4	2	0	0	0
1980	3	0	0	0	0	0	0	0	0	0	0	1	18	235	558	679	652	350	194	138	76	25	5	0	1	0
1981	1	0	0	0	0	5	18	7	7	10	0	18	48	285	503	453	340	198	153	89	70	36	9	4	0	0
1981	2	0	0	0	0	0	0	0	0	2	1	8	29	88	160	265	292	228	108	35	32	24	3	1	0	0
1981	3	0	0	0	0	0	0	0	0	0	0	0	2	8	86	230	318	300	220	89	29	15	2	0	1	0
1982	1	0	0	0	0	0	0	0	1	1	14	22	30	215	381	520	550	468	298	167	100	78	47	13	3	2
1982	2	0	0	0	0	0	0	0	0	0	9	43	17	102	208	164	211	164	133	80	48	11	7	3	3	0
1982	3	0	0	0	0	0	0	0	1	0	1	15	35	107	270	512	830	1195	1101	639	240	82	35	9	4	2
1983	1	0	0	0	0	0	0	0	1	3	21	51	178	1231	1673	2160	2944	3606	3254	2018	876	390	220	117	48	9
1983	2	0	0	0	0	0	0	0	0	1	4	18	24	118	414	454	580	676	704	520	368	154	55	19	10	0
1983	3	0	0	0	0	0	0	1	0	0	0	4	28	129	459	1163	1262	1550	1779	1565	993	477	148	37	9	6
1984	1	0	0	0	0	0	1	0	4	11	21	22	20	191	414	614	1188	1473	1370	833	400	177	60	31	20	3
1984	2	0	0	0	0	0	2	0	0	2	3	10	8	54	232	468	960	1290	1095	774	524	374	158	36	11	3
1984	3	0	0	0	0	0	0	1	2	12	53	250	643	1558	2738	6857	12095	15376	15438	12475	8243	4156	1555	465	143	43
1985	2	0	0	0	0	0	0	0	0	0	1	3	25	221	348	177	346	628	849	710	526	392	216	96	21	2
1985	3	0	0	0	0	0	1	0	0	5	28	167	756	5832	16308	14473	11108	18384	25332	19838	11750	6227	2938	1006	252	64
1986	1	0	0	0	0	0	0	0	7	23	51	84	278	1093	1464	1354	1181	2186	3783	3595	2082	911	360	107	26	3
1986	2	0	0	0	0	0	0	0	0	0	0	0	0	0	19	29	47	23	21	32	14	9	3	3	0	0
1986	3	0	0	0	0	0	0	0	0	0	18	154	610	2194	5080	14156	23223	20331	10705	10312	8875	4920	2286	869	324	85
1987	1	0	0	0	0	0	0	0	1	10	38	291	983	3411	3420	5818	10732	12540	10019	9453	7603	3871	1490	422	145	26
1987	3	0	0	0	3	0	0	0	2	7	26	130	511	4041	17126	27487	22822	24411	26687	19727	10159	6334	3638	1480	399	134

Table 2.8–Length frequencies of Pacific cod in the post-1988 trawl fishery by year, period, and length bin.

		Length Bin																								
Yr.	Per	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1989	1	0	0	3	3	1	0	29	217	497	799	721	961	3128	4368	4678	5713	7070	8599	8291	6310	3853	1882	917	391	144
1989	2	0	0	0	0	0	0	0	0	1	0	4	3	20	68	109	136	142	79	39	9	1	0	1	0	0
1989	3	0	0	0	0	1	6	7	13	32	53	49	33	90	54	36	83	92	88	22	6	4	0	0	0	0
1990	1	0	0	3	4	14	85	312	710	953	888	715	539	1148	2576	4417	7339	9969	10306	9376	6405	4195	2266	1280	480	163
1990	2	0	0	0	0	0	0	0	2	2	6	6	17	106	377	772	1048	1631	1566	1623	1221	655	457	206	80	32
1990	3	0	0	0	0	0	0	0	0	1	2	14	42	13	30	17	16	49	17	19	16	10	0	2	0	2
1991	1	0	1	5	6	15	71	452	1230	1329	1232	1288	1713	5172	6133	6560	9202	12298	12683	10962	7771	5103	2937	1517	766	281
1991	2	1	0	1	1	2	2	7	9	16	32	25	27	103	129	216	251	300	319	219	200	136	62	18	1	6
1992	1	0	3	9	15	21	67	200	631	1310	1664	2488	4704	9607	7198	6648	6782	8239	8016	7777	5712	3853	2326	1291	517	208
1993	1	0	0	5	8	23	56	254	1164	1666	1780	4496	7742	11709	10367	9951	7408	5314	4343	3901	3540	3128	2163	1472	806	341
1994	1	0	1	5	5	24	106	610	2149	3791	3227	1938	2981	9909	14285	14434	11718	11710	9933	6337	4075	2739	1764	1161	623	314
1995	1	0	0	12	28	46	160	306	448	495	707	2597	5806	9110	5979	7066	8171	8721	7021	4381	2782	1824	1195	772	540	408
1996	1	1	6	13	25	29	51	382	1066	1319	1118	1145	2429	8755	14699	13711	9877	10959	11919	9647	6868	4308	2875	1607	911	575
1996	2	0	0	0	0	0	0	2	2	5	10	11	35	112	164	186	106	125	97	160	107	16	0	0	1	0
1996	3	0	0	0	0	0	0	1	0	3	1	13	51	132	149	275	322	292	287	305	436	454	388	220	104	40
1997	1	1	4	17	80	97	65	326	1261	2372	2398	1778	2027	7423	8553	11653	16352	16489	12167	7909	5444	4105	2800	1846	1060	620
1997	2	0	1	0	4	5	1	4	4	8	8	12	13	31	42	38	34	20	24	15	8	2	0	0	1	0
1998	1	0	1	7	4	7	114	744	1464	1423	1113	969	1398	5031	6020	6694	10192	14965	16533	10659	5972	3531	2880	2293	1631	1107
1998	2	0	0	0	0	1	0	0	1	31	61	71	47	110	242	298	270	195	125	83	36	12	9	5	10	6
1998	3	0	0	0	0	0	0	1	2	3	12	37	60	135	172	249	177	190	211	258	270	160	74	68	46	22
1999	1	4	0	1	6	5	10	108	421	412	382	1039	2515	5006	3143	3270	3992	5218	5560	4722	3617	2327	1295	818	592	382
1999	2	0	0	0	0	0	0	0	0	0	0	1	5	31	31	32	30	21	9	15	12	15	10	5	6	5
1999	3	0	0	0	0	0	0	0	2	1	0	2	18	51	114	164	145	144	121	96	88	82	53	36	14	5
2000	1	0	0	0	2	2	7	63	187	173	236	559	1075	3035	4364	4870	4763	4839	5349	4673	3869	3230	2655	1546	952	636
2000	2	0	0	0	0	0	0	1	4	2	4	13	18	41	76	67	34	22	8	5	6	2	1	0	0	0
2000	3	0	0	0	0	0	0	0	0	0	0	0	0	3	13	20	12	8	6	3	0	1	1	0	0	0
2001	1	0	0	2	1	3	4	22	43	111	176	112	173	922	1483	2119	3376	4045	4026	2853	2193	1618	1195	840	531	276
2001	2	0	0	5	12	10	14	5	10	23	57	93	79	212	506	433	394	352	247	137	62	58	31	30	15	2
2001	3	0	0	0	0	0	1	2	8	12	8	21	33	80	109	200	199	202	175	109	68	33	15	14	10	5
2002	1	0	0	0	5	12	23	75	323	538	544	528	633	1764	2090	2194	3639	5050	5538	4606	3421	2436	1449	841	651	384
2002	2	0	0	0	4	5	3	10	54	171	206	179	115	135	158	175	123	93	88	68	50	24	16	10	3	2

Table 2.9–Length frequencies of Pacific cod in the post-1988 longline fishery by year, period, and length bin.

		Length Bin																								
Yr.	Per	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1990	1	0	0	0	0	0	0	0	0	0	0	4	12	163	784	1700	2796	3536	3080	2490	1599	1216	728	480	219	93
1990	2	0	0	0	0	0	0	6	6	24	56	136	238	794	2391	5893	10108	12945	12636	10237	7314	5084	3262	2200	889	315
1990	3	0	0	0	0	0	0	1	3	1	12	18	56	348	1644	5170	9453	11864	11121	8939	6057	3593	2102	1291	598	279
1991	1	0	0	0	0	0	0	0	5	14	30	114	306	1052	2487	5075	8929	11159	9547	6917	4040	2444	1331	780	311	130
1991	2	0	0	0	0	0	0	0	5	9	19	35	143	773	2130	4733	8310	10823	12060	10930	8769	6004	3203	1778	793	291
1991	3	0	0	0	1	3	18	33	39	62	127	207	467	1723	4038	7030	10634	13041	14086	13443	10791	7589	4290	2527	1104	440
1992	1	0	0	0	2	0	3	5	42	90	312	1253	3300	10451	14863	15640	19126	23004	20775	15837	11594	7556	4380	2455	1057	407
1992	2	0	0	0	0	3	2	3	21	66	174	574	1325	6719	13151	13754	15857	17833	16704	14043	11802	8990	6331	4035	2045	831
1992	3	0	0	0	0	0	0	0	1	6	19	52	154	765	2375	2564	2390	2741	2404	1939	1595	1267	888	565	298	106
1993	1	0	0	1	0	1	6	16	76	186	450	1482	3328	10312	20462	27089	23370	17302	14383	12020	9965	6845	3850	1953	926	314
1994	1	0	0	0	3	3	12	23	40	91	223	551	1472	7088	17414	29142	38186	32928	19177	9869	6051	4280	3011	1766	930	325
1994	3	0	0	0	0	0	0	2	8	12	57	145	268	952	3070	5831	8261	9569	7327	4226	2341	1425	914	505	296	141
1995	1	0	0	0	2	5	6	13	24	60	186	1059	3031	8219	14024	23789	30478	28823	18233	8432	3841	1961	1172	730	445	206
1995	2	0	0	0	0	0	0	0	0	0	1	0	3	10	33	55	79	56	29	37	38	27	15	9	0	0
1995	3	0	0	1	0	0	1	2	21	25	50	219	522	2929	7080	8279	9857	12273	11397	8717	5585	3365	2040	1402	714	287
1996	1	0	0	0	0	0	0	1	20	73	192	604	1794	9116	19703	26399	29777	28680	21120	12783	6741	3465	1691	992	518	382
1996	2	0	0	0	0	0	0	0	0	0	0	0	0	9	27	23	27	17	15	15	14	6	3	0	0	0
1996	3	0	0	0	0	0	1	0	4	15	83	182	404	1626	5549	11617	14477	11224	8332	7296	5950	4217	2391	1149	562	306
1997	1	0	0	0	0	0	1	5	18	92	224	571	1700	8606	17788	30652	40069	35267	21243	12004	7165	4417	2557	1322	651	389
1997	2	0	0	0	0	0	0	0	0	0	0	1	1	4	6	18	18	15	16	5	8	6	4	4	3	0
1997	3	0	0	1	2	3	13	20	89	160	288	621	1673	4814	9408	15198	20854	26965	25031	17322	8992	6074	3767	1977	853	364
1998	1	0	0	0	0	1	9	19	94	224	414	957	2524	8417	13159	18857	27872	30580	24229	13821	7243	4858	3787	2748	1747	1261
1998	2	0	0	0	0	0	0	0	0	0	1	1	6	22	4	9	7	4	1	2	3	0	2	0	0	0
1998	3	1	0	0	1	32	23	46	45	93	370	1928	4087	9736	15515	22466	26645	30947	28225	21358	13610	7212	3900	2469	1211	635
1999	1	0	0	0	2	2	0	4	22	60	220	1263	3731	8701	8787	10336	12449	12238	10724	7083	4170	2019	1037	624	408	347
1999	2	0	0	0	0	0	0	0	0	6	13	44	135	981	1548	1315	1398	1400	1230	816	573	328	175	77	42	14
1999	3	1	0	0	0	0	1	10	27	61	115	371	707	3684	7968	7048	6468	6890	6175	4308	3091	1886	1110	554	359	231
2000	1	2	0	0	0	0	1	5	16	50	189	679	1627	6534	10526	11488	9991	8549	6638	4465	3133	2504	1923	1339	957	797
2000	2	0	0	0	0	0	0	0	0	0	4	10	27	248	654	1256	1910	1616	1240	891	701	500	397	250	156	100
2000	3	1	8	0	0	0	1	3	7	15	71	431	1300	4358	10130	16501	21226	16982	10164	6387	4077	2569	1573	881	569	443
2001	1	1	0	0	0	2	2	5	27	117	363	581	1283	5348	10260	14341	16442	13783	8606	4957	2958	1878	1393	955	705	552
2001	2	0	0	0	0	0	0	2	10	26	103	211	407	1449	3133	4343	4736	4615	3548	1825	1100	597	408	322	332	264
2001	3	0	0	0	1	4	0	5	21	56	236	1040	2147	6079	10320	16069	18724	18097	13810	6921	3436	1789	1248	960	679	593
2002	1	1	2	5	5	7	14	19	89	191	332	1051	2650	6212	7174	9911	13875	12922	8404	3937	1860	843	467	307	115	66
2002	2	0	0	0	0	1	1	2	8	13	49	123	262	1017	1832	1958	1775	1806	1310	794	361	182	107	38	20	3

Table 2.10–Length frequencies of Pacific cod in the pot fishery by year, period, and length bin.

		Length Bin																								
Yr.	Per	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1990	2	0	0	0	0	0	0	0	0	0	0	0	1	7	42	74	141	230	293	220	229	138	81	45	3	2
1990	3	0	0	0	0	0	0	0	0	0	0	0	1	3	10	116	512	1149	1146	1360	701	391	260	109	11	3
1991	2	0	0	0	0	0	0	0	0	0	0	0	0	39	240	572	1106	1700	2050	1874	1636	875	414	155	35	5
1991	3	0	0	0	0	0	0	0	0	0	0	0	6	29	163	406	790	1444	2084	2236	1810	1218	637	290	101	29
1992	1	0	0	0	0	0	1	0	1	0	8	7	24	174	380	731	1875	3807	3583	2710	1776	1160	590	324	99	39
1992	2	0	0	0	0	0	0	1	2	5	36	103	438	2186	3592	4075	5205	6914	7708	7212	5139	3268	1601	710	261	113
1992	3	0	0	0	0	0	0	0	0	2	22	73	145	590	869	749	599	526	406	327	306	200	151	79	48	55
1993	1	0	0	0	0	0	0	0	0	0	0	8	28	320	824	1448	1968	1869	1621	1062	640	384	233	93	41	18
1994	1	0	0	0	0	0	0	0	0	0	1	19	125	727	2791	4384	4660	4567	3529	2371	1284	706	409	238	112	27
1994	3	0	0	0	0	0	0	0	0	5	3	10	25	152	576	1095	1255	1050	808	601	364	229	136	71	39	17
1995	1	0	0	0	0	0	0	0	0	1	4	45	242	1203	3094	6944	10101	9099	6435	3950	2408	1608	1394	826	222	84
1995	2	0	0	0	0	0	0	0	0	0	0	5	56	443	841	1540	2499	2682	2128	1816	1425	1139	1007	520	449	236
1995	3	0	0	0	0	0	0	0	0	0	1	0	16	275	821	1444	2240	2490	2142	1563	1158	787	449	201	125	29
1996	1	0	0	0	0	0	3	5	11	14	39	89	268	2272	6731	10936	13049	13395	10997	7115	4724	2883	1910	1123	588	241
1996	2	0	0	0	0	0	0	0	0	1	1	6	43	389	1293	2879	3807	3552	2788	2147	1939	1517	1126	771	513	291
1996	3	0	0	0	0	0	0	0	0	0	0	3	12	174	464	953	1766	1923	1526	1088	991	929	668	400	218	84
1997	1	0	0	0	0	1	0	0	1	3	15	38	82	647	2100	5113	9620	10616	6855	3690	1963	1239	838	530	311	197
1997	2	0	0	0	0	0	0	0	1	0	1	7	22	164	454	973	1685	2434	2523	1440	704	477	393	270	143	69
1997	3	0	0	0	0	0	0	0	1	0	1	7	22	164	454	973	1685	2434	2523	1440	704	477	393	270	143	69
1998	1	0	0	0	0	1	0	0	0	2	4	17	93	695	1363	2166	4743	6257	5386	3157	1369	579	372	213	118	60
1998	2	0	0	0	0	0	0	0	0	0	0	5	12	159	524	934	1372	1824	1709	1051	520	280	210	131	111	57
1998	3	0	0	0	0	0	0	0	1	0	3	8	10	70	257	405	605	730	788	587	396	247	147	130	72	66
1999	1	0	0	0	0	0	0	1	2	2	6	17	106	918	1497	2389	3677	3882	3557	2484	1586	958	656	392	332	172
1999	2	0	0	0	0	0	0	0	0	0	0	2	7	58	123	151	239	239	257	198	170	148	116	72	51	44
1999	3	0	0	0	0	0	0	0	0	4	12	21	53	305	793	1153	1122	1255	1086	835	696	585	442	249	202	109
2000	1	0	0	0	0	0	0	0	1	2	2	12	112	934	2545	4019	4085	3753	3482	2412	1715	1125	882	487	256	216
2000	3	0	0	0	0	0	0	0	0	0	1	1	3	39	87	134	149	62	25	8	0	2	1	0	0	0
2001	1	4	0	1	0	0	0	0	0	0	0	3	13	234	796	2200	4015	4021	2277	1046	485	316	232	168	78	96
2001	2	0	0	0	0	0	0	0	0	0	0	0	0	0	12	45	77	103	93	61	33	5	7	4	6	1
2001	3	0	0	0	0	0	0	2	2	1	4	4	14	155	618	1313	1543	1768	1322	674	438	267	156	93	48	25
2002	1	0	0	0	0	0	0	0	0	0	0	4	16	130	583	1516	2800	2810	1776	761	289	131	78	39	20	14
2002	2	0	0	0	0	0	0	0	0	0	0	1	2	3	15	38	59	56	53	34	29	7	12	2	0	1

Table 2.11–Length frequencies of Pacific cod in the trawl survey by year (all surveys take place in period 2). Numbers shown are survey estimates of population numbers at length, rescaled so that the sum equals the total size of the actual survey length sample.

		Length Bin																								
Yr.	Per	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1979	2	0	5	44	186	374	457	694	1764	2393	1884	1171	618	202	70	44	51	29	8	0	3	1	1	0	0	0
1980	2	0	6	85	241	82	42	224	687	929	1320	1542	2062	1364	893	333	100	33	31	19	6	2	0	0	0	0
1981	2	0	20	156	330	278	32	100	330	653	724	511	1063	1396	1746	1215	812	398	156	39	27	13	1	0	0	0
1982	2	16	84	205	132	35	27	124	384	732	718	391	769	1179	1256	1232	1135	821	450	192	80	26	8	3	0	0
1983	2	278	996	939	460	109	23	100	264	405	294	163	483	891	1024	1069	891	700	514	247	111	22	14	3	1	0
1984	2	43	88	66	120	252	762	1380	1426	858	389	200	291	361	481	708	783	713	478	320	152	83	36	10	1	0
1985	2	88	325	573	893	1004	387	179	362	544	580	703	1194	815	392	282	322	408	401	294	148	69	24	10	4	0
1986	2	91	286	320	99	75	452	1163	1257	1040	711	359	396	573	869	776	406	268	296	244	171	79	48	13	8	0
1987	2	18	72	248	385	258	179	413	847	729	580	600	1231	1089	768	551	604	581	378	193	151	61	45	15	6	0
1988	2	9	53	80	91	109	236	282	393	666	627	493	987	1102	1310	1086	833	559	414	293	234	75	33	28	7	0
1989	2	17	137	316	224	69	37	92	102	147	350	347	565	709	1218	1308	1138	941	800	632	326	234	146	87	59	0
1990	2	203	491	689	357	132	124	263	303	323	277	174	160	169	224	349	408	276	262	170	123	82	33	25	10	1
1991	2	141	408	447	381	228	262	595	867	912	611	349	249	259	327	260	226	211	181	108	107	49	20	22	7	1
1992	2	18	468	451	565	514	455	891	1092	872	560	462	889	699	564	244	233	186	108	101	91	54	38	30	15	1
1993	2	114	924	1087	981	677	213	247	614	847	666	489	845	842	665	398	267	230	85	62	49	36	21	24	15	6
1994	2	18	145	291	361	327	446	957	1924	2082	1121	443	685	1051	964	1058	920	565	288	92	46	33	60	15	22	8
1995	2	29	74	135	208	77	172	460	691	580	705	1064	1575	1017	617	434	484	326	253	133	84	41	27	18	9	3
1996	2	14	65	164	198	110	103	357	699	677	526	499	744	1477	1404	908	499	288	237	148	109	71	25	16	7	3
1997	2	91	472	601	728	507	140	215	481	628	451	407	399	918	809	842	583	436	215	105	60	40	26	10	4	1
1998	2	30	262	334	74	46	311	1151	1837	1396	655	379	367	659	458	378	391	333	244	132	64	33	29	9	10	1
1999	2	71	335	286	113	141	415	760	874	667	719	1169	1648	1854	768	493	447	337	252	130	89	62	37	24	7	2
2000	2	175	918	1310	505	54	141	488	785	604	564	749	958	1720	1419	894	537	266	188	99	79	57	33	19	3	0
2001	2	95	640	1815	2110	1011	407	903	1994	2550	1618	706	486	1193	1278	1080	819	515	257	123	71	34	22	14	4	5
2002	2	31	192	374	352	105	207	662	1456	1446	1004	791	1216	1579	880	611	546	368	209	104	49	19	16	15	3	2

Table 2.12--Biomass, standard error, 95% confidence interval (CI), and population numbers of Pacific cod estimated by NMFS' annual bottom trawl survey of the EBS shelf. All figures except population numbers are expressed in metric tons. Population numbers are expressed in terms of individual fish.

Year	Biomass	Standard Error	Lower 95% CI	Upper 95% CI	Numbers
1979	754,314	97,844	562,539	946,089	1,530,429,650
1980	905,344	87,898	733,063	1,077,624	1,084,147,540
1981	1,034,629	123,849	791,885	1,277,373	794,619,624
1982	1,020,550	73,392	876,701	1,164,399	583,715,089
1983	1,176,305	121,606	937,958	1,414,651	725,351,369
1984	1,001,940	64,127	876,251	1,127,629	636,948,300
1985	961,050	51,453	860,203	1,061,896	800,070,473
1986	1,134,106	71,813	993,353	1,274,858	843,460,794
1987	1,142,450	71,439	1,002,430	1,282,468	754,269,021
1988	959,544	76,284	810,028	1,109,060	509,336,483
1989	960,436	69,157	824,888	1,095,984	339,719,445
1990	708,551	53,728	603,245	813,857	435,856,535
1991	532,590	41,678	450,902	614,279	496,841,261
1992*	546,707	45,754	457,030	636,383	577,416,832
1993	690,524	54,934	582,853	798,196	851,866,426
1994	1,368,109	254,435	869,416	1,866,802	1,237,760,162
1995	1,003,046	92,677	821,400	1,184,692	757,576,445
1996	890,793	120,522	652,160	1,129,426	609,304,214
1997	604,881	69,250	466,382	743,380	487,429,700
1998	534,141	42,942	449,116	619,166	514,321,475
1999	583,259	50,622	483,028	683,490	500,692,872
2000	528,466	43,037	443,253	613,679	481,358,109
2001	830,479	75,675	679,130	981,829	980,493,794
2002	616,923	69,586	477,750	756,096	564,115,880

*During the 1992 field season, 18 stations were omitted from the standard survey grid due to severe weather and vessel problems. In 1989, 1990, and 1991, these 18 stations represented, on average, 2.2% and 2.8% of the total Pacific cod biomass and numbers, respectively. The 1992 point estimates and confidence interval shown above have been adjusted upward proportionately.

Table 2.13–Magnitude of hydroacoustic, longline, and bottom trawl survey removals (t) in the EBS and AI from 1977 through 2001. Cells with an entry of zero indicate that survey removals amounted to less than 0.5 t, whereas cells with no entry indicate either that there was no survey in that region and year or that no data from any such surveys are available.

Year	Eastern Bering Sea				Aleutians			
	Acoustic	Longline	Trawl	Total	Acoustic	Longline	Trawl	Total
1977			4	4				
1978	1		25	26				
1979	0	4	61	65		10		10
1980		5	37	42		16	64	80
1981		8	94	102		23		23
1982	1	82	115	198		42	153	195
1983		79	95	174		36	102	138
1984		94	52	145		42		42
1985	0	111	100	211		58		58
1986		121	41	162		58	98	155
1987		126	41	167		58		58
1988	0	102	71	173		54		54
1989	1	160	56	217		43		43
1990	1	133	50	184		56		56
1991	2	101	74	177		72	37	109
1992	0	57	17	74		81		81
1993	0	76	25	101		56		56
1994	2	98	49	149		60	62	122
1995	2	0	52	54		0		0
1996	0		32	33		11		11
1997	0	24	26	50			20	20
1998	0		21	39		18		
1999	1	19	26	46				
2000	1		20	36		15	24	24
2001	0	22	34	56				
2002	1		26	27		12	87	99

Table 2.14–Symbols used in the Synthesis assessment model for Pacific cod (page 1 of 2).

Indices	
a	age group
g	gear type
i	time interval
j	size bin
y	year

Dimensions	
a_{min}	age of youngest group
a_{max}	age of oldest group
g_{max}	number of gear types
i_{max}	number of time intervals in each year
j_{max}	number of size bins
y_{max}	number of years

Special Values of Indices	
a_{rec}	index of age group used to assess recruitment strength
g_{sur}	index of survey gear type
i_{spa}	index of time interval during which spawning occurs
i_{sur}	index of time interval during which survey occurs

Operators	
$e(y\|g)$	returns the era containing year y given gear type g
l_{mid}	returns the length corresponding to the midpoint of bin j
l_{min}	returns the smallest length contained in bin j
t_{dur}	returns the duration (in years) of time interval i

Continuous Variables	
α	age
λ	length
τ	time

Special Values of Continuous Variables	
α_1	first reference age used in length-at-age relationship (in years)
α_2	second reference age used in length-at-age relationship (in years)
λ_{min}	minimum length used in assessment
λ_{max}	maximum length used in assessment
τ_{spa}	annual time of spawning (in years)
τ_{sur}	annual time of survey (in years)

Table 2.14–Symbols used in the Synthesis assessment model for Pacific cod (page 2 of 2).

Functions of Age or Length	
$h(\lambda \mid \alpha)$	probability density function describing distribution of length, conditional on age
$l(\alpha)$	length at age
$p(\lambda)$	proportion mature at length
$s(\lambda \mid g, y)$	selectivity at length, conditional on gear type and year
$w(\lambda)$	weight at length
$x(\alpha)$	standard deviation associated with the length-at-age relationship, as a function of age

Arrays Generated by Synthesis	
b_y	biomass of population aged $a \geq a_{rec}$ at start of year y
c_y	spawning biomass at time of spawning in year y
d_y	survey biomass at time of survey in year y
$n_{a,y,i}$	population numbers at age a, year y, and time interval i
$u_{a,y}$	population numbers at time of spawning at age a and year y
$v_{a,y}$	population numbers at time of survey at age a and year y
$z_{a,i,j}$	proportion of length distribution falling within size bin j at age a and time interval i

Parameters Used by Synthesis	
$F_{g,y,i}$	instantaneous fishing mortality rate at each gear g, year y, and time i for which catch>0
K	Brody's growth parameter
L_1	length at age α_1
L_2	length at age α_2
M	instantaneous natural mortality rate
N_a	initial population numbers at each age $a > a_{min}$
P_1	length at point of inflection in maturity schedule
P_2	relative slope at point of inflection in maturity schedule
Q	survey catchability
R_y	recruitment at age a_{min} in year y
$S_{1,g,e(y\|g)}$	selectivity at minimum length in gear type g and era e
$S_{2,g,e(y\|g)}$	length at inflection in ascending part of selectivity schedule in gear type g and era e
$S_{3,g,e(y\|g)}$	relative slope at inflection in ascending part of selectivity schedule in gear type g and era e
$S_{4,g,e(y\|g)}$	length at maximum selectivity in gear type g and era e
$S_{5,g,e(y\|g)}$	selectivity at maximum length in gear type g and era e
$S_{6,g,e(y\|g)}$	length at inflection in descending part of selectivity schedule in gear type g and era e
$S_{7,g,e(y\|g)}$	relative slope at inflection in descending part of selectivity schedule in gear type g and era e
W_1	weight-length proportionality
W_2	weight-length exponent
X_1	standard deviation of length evaluated at age α_1
X_2	standard deviation of length evaluated at age α_2

Table 2.15–Dimensions and special values of indices and variables used in the Pacific cod assessment. Symbols are defined in Table 2.14.

Dimensions

Term	Value	Comments/Rationale
a_{min}	1	assumed minimum age group observed in the trawl survey
a_{max}	12	a convenient place to insert an “age-plus” category
g_{max}	6	early trawl, late trawl, longline, pot, pre-1982 survey, post-1981 survey
i_{max}	3	January through March, June through August, September through December
j_{max}	25	bin boundaries are given in the “Data” section of the text
y_{max}	24	1978 through 2001

Special Values of Indices

Term	Value	Comments/Rationale
a_{rec}	3	age traditionally used to indicate first significant recruitment to the fishery
g_{sur}	6	index of post-1981 survey gear type
i_{spa}	1	March (see τ_{spa} below) falls within the first intra-annual time period
i_{sur}	2	July (see τ_{sur} below) falls within the second intra-annual time period

Special Values of Continuous Variables

Term	Value	Comments/Rationale
α_1	1.5	assumed age of youngest fish seen in the trawl survey
α_2	12.0	set equal to the lower bound of the age-plus group for convenience
λ_{min}	9	close to the length of the smallest fish seen by the survey in a typical year
λ_{max}	115	close to the length of the largest fish seen by the survey in a typical year
τ_{spa}	(3-1)/12	March appears to be the month of peak spawning in the observer data
τ_{sur}	(7-1)/12	July is the approximate mid-point of the June-August trawl survey season

Table 2.16–Partitioning the list of parameters used in the Synthesis model of Pacific cod into those that are estimated independently (i.e., outside) of Synthesis and those that are estimated conditionally (i.e., inside of Synthesis).

Parameters Estimated Independently	
L_1	length at age α_1
M	instantaneous natural mortality rate
P_1	length at point of inflection in maturity schedule
P_2	relative slope at point of inflection in maturity schedule
Q	survey catchability
W_1	weight-length proportionality
W_2	weight-length exponent
X_1	standard deviation of length evaluated at age α_1
X_2	standard deviation of length evaluated at age α_2

Parameters Estimated Conditionally	
$F_{g,y,i}$	instantaneous fishing mortality rate at each gear g, year y, and time i for which catch>0
K	Brody's growth parameter
L_2	length at age α_2
N_a	initial population numbers at each age $a > a_{min}$
R_y	recruitment at age a_{min} in year y
$S_{1,g,e(y\|g)}$	selectivity at minimum length in gear type g and era e
$S_{2,g,e(y\|g)}$	length at inflection in ascending part of selectivity schedule in gear type g and era e
$S_{3,g,e(y\|g)}$	relative slope at inflection in ascending part of selectivity schedule in gear type g and era e
$S_{4,g,e(y\|g)}$	length at maximum selectivity in gear type g and era e
$S_{5,g,e(y\|g)}$	selectivity at maximum length in gear type g and era e
$S_{6,g,e(y\|g)}$	length at inflection in descending part of selectivity schedule in gear type g and era e
$S_{7,g,e(y\|g)}$	relative slope at inflection in descending part of selectivity schedule in gear type g and era e

Table 2.17–Pacific cod commercial fishery length sample sizes used in the multinomial distribution. (These values correspond to the square roots of the true sample sizes shown in Table 2.5.)

Year	Trawl Fishery			Longline Fishery			Pot Fishery		
	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3
1978	25	0	56	54	70	50	0	0	0
1979	41	0	27	107	50	52	0	0	0
1980	37	9	18	51	37	54	0	0	0
1981	11	0	39	47	36	36	0	0	0
1982	24	15	41	54	35	71	0	0	0
1983	111	35	121	137	64	98	0	0	0
1984	101	67	67	83	77	287	0	0	0
1985	174	39	55	0	68	367	0	0	0
1986	169	43	50	136	14	323	0	0	0
1987	215	82	145	265	0	406	0	0	0
1988	322	0	54	0	0	0	0	0	0
1989	242	25	26	0	0	0	0	0	0
1990	253	99	16	137	273	250	0	39	76
1991	298	46	0	234	266	303	0	103	106
1992	282	0	0	390	366	142	131	220	72
1993	286	0	0	393	0	0	103	0	0
1994	322	0	0	415	0	213	161	0	80
1995	262	0	0	380	20	273	218	130	117
1996	323	34	59	405	12	275	276	152	106
1997	327	17	0	430	10	380	209	108	108
1998	329	53	55	404	8	437	163	94	67
1999	212	15	34	290	100	226	150	43	94
2000	217	17	8	267	100	313	161	0	23
2001	162	53	36	291	166	320	126	21	92
2002	192	41	n/a	265	108	n/a	105	18	n/a

Table 2.18–Estimates of Pacific cod fishing mortality rates, expressed on an annual time scale (page 1 of 2). Empty cells indicate that no catch was recorded.

Model 1

Year	Trawl			Longline			Pot		
	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3
1978	0.11	0.23	0.25	0.02	0.02	0.03			
1979	0.07	0.16	0.09	0.01	0.01	0.00			
1980	0.04	0.06	0.08	0.01	0.00	0.02			
1981	0.03	0.05	0.06	0.00	0.00	0.01			
1982	0.03	0.05	0.03	0.00	0.00	0.00			
1983	0.05	0.05	0.04	0.00	0.00	0.00			
1984	0.06	0.05	0.04	0.01	0.00	0.03			
1985	0.07	0.06	0.04	0.02	0.00	0.04			
1986	0.07	0.06	0.04	0.01	0.00	0.03			
1987	0.08	0.03	0.03	0.03	0.00	0.05			
1988	0.16	0.05	0.08	0.00	0.00	0.00	0.00	0.00	0.00
1989	0.16	0.03	0.03	0.01	0.01	0.01	0.00	0.00	0.00
1990	0.14	0.02	0.02	0.02	0.05	0.04		0.00	0.00
1991	0.17	0.04	0.01	0.05	0.08	0.08	0.00	0.00	0.01
1992	0.11	0.03	0.01	0.12	0.10	0.02	0.01	0.02	0.00
1993	0.13	0.02	0.02	0.12	0.00	0.00	0.01	0.00	
1994	0.12	0.02	0.04	0.13	0.00	0.06	0.01		0.01
1995	0.17	0.03	0.03	0.15	0.00	0.08	0.03	0.01	0.01
1996	0.15	0.01	0.02	0.14	0.00	0.08	0.04	0.03	0.01
1997	0.17	0.01	0.02	0.17	0.00	0.15	0.04	0.02	0.01
1998	0.10	0.02	0.03	0.15	0.00	0.12	0.02	0.01	0.01
1999	0.11	0.01	0.01	0.17	0.01	0.10	0.03	0.01	0.01
2000	0.11	0.02	0.01	0.12	0.01	0.15	0.05		0.00
2001	0.06	0.03	0.02	0.11	0.03	0.17	0.04	0.00	0.02
2002	0.09	0.04	0.01	0.15	0.06	0.14	0.03	0.00	0.01

Table 2.18–Estimates of Pacific cod fishing mortality rates, expressed on an annual time scale (page 2 of 2). Empty cells indicate that no catch was recorded.

Model 2

Year	Trawl			Longline			Pot		
	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3
1978	0.11	0.23	0.25	0.02	0.02	0.03			
1979	0.07	0.16	0.09	0.01	0.01	0.00			
1980	0.04	0.06	0.08	0.01	0.00	0.02			
1981	0.03	0.05	0.06	0.00	0.00	0.01			
1982	0.03	0.05	0.03	0.00	0.00	0.00			
1983	0.05	0.05	0.04	0.00	0.00	0.00			
1984	0.06	0.05	0.04	0.01	0.00	0.03			
1985	0.07	0.06	0.04	0.02	0.00	0.04			
1986	0.07	0.06	0.04	0.01	0.00	0.03			
1987	0.08	0.03	0.03	0.03	0.00	0.05			
1988	0.16	0.06	0.08	0.00	0.00	0.00			
1989	0.16	0.03	0.03	0.01	0.01	0.01	0.00	0.00	0.00
1990	0.14	0.03	0.02	0.02	0.05	0.04		0.00	0.00
1991	0.17	0.04	0.01	0.05	0.08	0.09	0.00	0.00	0.01
1992	0.11	0.04	0.01	0.12	0.11	0.02	0.01	0.02	0.00
1993	0.14	0.02	0.02	0.13	0.00	0.00	0.01	0.00	
1994	0.12	0.02	0.04	0.14	0.00	0.06	0.01		0.01
1995	0.18	0.03	0.03	0.17	0.00	0.09	0.03	0.01	0.01
1996	0.16	0.01	0.03	0.15	0.00	0.08	0.05	0.03	0.01
1997	0.18	0.01	0.02	0.18	0.00	0.16	0.04	0.02	0.01
1998	0.11	0.02	0.03	0.16	0.00	0.13	0.03	0.01	0.01
1999	0.12	0.01	0.01	0.19	0.01	0.10	0.03	0.01	0.01
2000	0.15	0.02	0.02	0.12	0.01	0.14	0.06		0.00
2001	0.08	0.03	0.02	0.10	0.03	0.16	0.04	0.00	0.02
2002	0.12	0.04	0.01	0.14	0.06	0.12	0.04	0.00	0.01

Table 2.19–Estimates of Pacific cod recruitment at age 1 and initial numbers at age (in millions of fish).

Recruitment at age 1

Year	Model 1	Model 2
1978	1484	1469
1979	666	665
1980	757	760
1981	601	601
1982	194	196
1983	1097	1088
1984	331	329
1985	892	877
1986	555	537
1987	339	333
1988	191	192
1989	253	249
1990	615	597
1991	611	581
1992	352	340
1993	680	650
1994	335	322
1995	275	264
1996	259	253
1997	557	566
1998	365	373
1999	302	305
2000	535	578
2001	700	784
2002	229	252

Numbers at age

Age	Model 1	Model 2
2	253	255
3	93	92
4	102	101
5	0	0
6	11	11
7	3	3
8	0	0
9	0	0
10	0	0
11	1	1
12	0	0

Table 2.20–Estimates of Pacific cod selectivity parameters. The first column in each half of the table lists the parameter families for which the remaining columns contain era-specific estimates.

Model 1

Trawl (Jan-May)	1978-88	1989-02
$S_{1,g,e(y\|g)}$	0.00	0.00
$S_{2,g,e(y\|g)}$	56.64	52.65
$S_{3,g,e(y\|g)}$	0.14	0.16
$S_{4,g,e(y\|g)}$	88.39	87.23
$S_{5,g,e(y\|g)}$	0.86	0.54
$S_{6,g,e(y\|g)}$	88.98	93.87
$S_{7,g,e(y\|g)}$	1.40	0.34
Trawl (Jun-Dec)	1978-88	1989-02
$S_{1,g,e(y\|g)}$	0.00	0.00
$S_{2,g,e(y\|g)}$	51.67	60.63
$S_{3,g,e(y\|g)}$	0.19	0.17
$S_{4,g,e(y\|g)}$	93.16	86.17
$S_{5,g,e(y\|g)}$	0.95	0.90
$S_{6,g,e(y\|g)}$	93.16	86.17
$S_{7,g,e(y\|g)}$	4.86	0.75
Longline	1978-88	1989-02
$S_{1,g,e(y\|g)}$	0.00	0.00
$S_{2,g,e(y\|g)}$	57.36	59.91
$S_{3,g,e(y\|g)}$	0.27	0.25
$S_{4,g,e(y\|g)}$	76.73	85.21
$S_{5,g,e(y\|g)}$	0.53	0.35
$S_{6,g,e(y\|g)}$	83.47	85.87
$S_{7,g,e(y\|g)}$	0.25	0.12
Pot	1978-88	1989-02
$S_{1,g,e(y\|g)}$	n/a	0.00
$S_{2,g,e(y\|g)}$	n/a	61.48
$S_{3,g,e(y\|g)}$	n/a	0.28
$S_{4,g,e(y\|g)}$	n/a	80.02
$S_{5,g,e(y\|g)}$	n/a	0.60
$S_{6,g,e(y\|g)}$	n/a	80.79
$S_{7,g,e(y\|g)}$	n/a	0.24
Survey	1978-81	1982-02
$S_{1,g,e(y\|g)}$	0.00	0.12
$S_{2,g,e(y\|g)}$	29.51	20.89
$S_{3,g,e(y\|g)}$	0.20	0.00
$S_{4,g,e(y\|g)}$	46.63	45.46
$S_{5,g,e(y\|g)}$	0.34	0.08
$S_{6,g,e(y\|g)}$	47.66	46.37
$S_{7,g,e(y\|g)}$	0.14	0.05

Model 2

Trawl (Jan-May)	1978-88	1989-99	2000-02
$S_{1,g,e(y\|g)}$	0.00	0.00	0.00
$S_{2,g,e(y\|g)}$	52.04	53.60	69.50
$S_{3,g,e(y\|g)}$	0.16	0.15	0.14
$S_{4,g,e(y\|g)}$	86.70	85.64	107.05
$S_{5,g,e(y\|g)}$	0.49	0.71	1.00
$S_{6,g,e(y\|g)}$	92.56	86.28	107.52
$S_{7,g,e(y\|g)}$	0.28	0.21	4.38
Trawl (Jun-Dec)	1978-88	1989-99	2000-02
$S_{1,g,e(y\|g)}$	0.00	0.00	0.00
$S_{2,g,e(y\|g)}$	60.04	53.22	48.75
$S_{3,g,e(y\|g)}$	0.17	0.19	0.19
$S_{4,g,e(y\|g)}$	85.64	97.09	80.23
$S_{5,g,e(y\|g)}$	0.86	0.85	0.54
$S_{6,g,e(y\|g)}$	85.64	97.09	81.00
$S_{7,g,e(y\|g)}$	0.55	0.00	0.24
Longline	1978-88	1989-99	2000-02
$S_{1,g,e(y\|g)}$	0.00	0.00	0.00
$S_{2,g,e(y\|g)}$	59.42	57.60	54.93
$S_{3,g,e(y\|g)}$	0.25	0.27	0.28
$S_{4,g,e(y\|g)}$	84.47	76.31	85.43
$S_{5,g,e(y\|g)}$	0.31	0.44	0.61
$S_{6,g,e(y\|g)}$	85.14	77.32	86.08
$S_{7,g,e(y\|g)}$	0.12	0.12	1.18
Pot	1978-88	1989-99	2000-02
$S_{1,g,e(y\|g)}$	n/a	0.00	0.00
$S_{2,g,e(y\|g)}$	n/a	61.30	60.42
$S_{3,g,e(y\|g)}$	n/a	0.27	0.31
$S_{4,g,e(y\|g)}$	n/a	78.64	78.96
$S_{5,g,e(y\|g)}$	n/a	0.55	0.46
$S_{6,g,e(y\|g)}$	n/a	79.44	79.75
$S_{7,g,e(y\|g)}$	n/a	0.14	0.31
Survey	1978-81	1982-02	
$S_{1,g,e(y\|g)}$	0.00	0.12	
$S_{2,g,e(y\|g)}$	29.35	20.82	
$S_{3,g,e(y\|g)}$	0.20	0.00	
$S_{4,g,e(y\|g)}$	46.21	45.25	
$S_{5,g,e(y\|g)}$	0.33	0.07	
$S_{6,g,e(y\|g)}$	47.24	46.16	
$S_{7,g,e(y\|g)}$	0.13	0.05	

Table 2.21–Time series of EBS Pacific cod age 3+ biomass, spawning biomass, and survey biomass as estimated by Models 1 and 2. All biomass figures are in t.

Year	Model 1			Model 2			Survey (obs)
	Age 3+	Spawning	Survey (est)	Age 3+	Spawning	Survey (est)	
1978	323	48		320	48		n/a
1979	476	79	559	474	79	555	754
1980	1062	137	920	1053	136	917	905
1981	1587	255	1061	1576	254	1063	1035
1982	2061	436	1192	2052	435	1206	1021
1983	2393	614	1117	2388	615	1135	1176
1984	2427	733	1075	2429	736	1090	1002
1985	2584	775	1107	2587	780	1120	961
1986	2548	777	1097	2553	783	1105	1134
1987	2627	781	1123	2627	788	1126	1142
1988	2630	779	1033	2621	784	1033	960
1989	2481	767	868	2465	770	866	960
1990	2227	740	711	2209	739	709	709
1991	1946	671	653	1927	669	646	533
1992	1762	569	708	1736	565	694	547
1993	1730	496	750	1690	490	730	691
1994	1717	482	773	1669	473	749	1368
1995	1754	471	764	1692	457	738	1003
1996	1672	457	683	1601	439	657	891
1997	1545	443	584	1471	423	562	605
1998	1355	412	562	1282	390	545	534
1999	1330	379	593	1267	357	585	583
2000	1320	360	590	1270	339	594	528
2001	1284	359	604	1251	343	620	830
2002	1320	356	676	1315	346	717	617

Table 2.22–Distribution of Pacific cod lengths (in cm) at age (mid-year) as defined by final parameter estimates. Lengths correspond to lower bounds of size bins. Columns sum to 1.0.

Len.	Age Group										
	1	2	3	4	5	6	7	8	9	10	11	12+
105	0	0	0	0	0	0	0	0.001	0.006	0.021	0.047	0.171
100	0	0	0	0	0	0	0.001	0.008	0.030	0.070	0.116	0.181
95	0	0	0	0	0	0	0.007	0.041	0.105	0.173	0.223	0.224
90	0	0	0	0	0	0.004	0.042	0.131	0.220	0.265	0.271	0.201
85	0	0	0	0	0.001	0.029	0.139	0.250	0.281	0.252	0.207	0.132
80	0	0	0	0	0.010	0.117	0.263	0.283	0.219	0.149	0.099	0.063
75	0	0	0	0.001	0.063	0.255	0.288	0.190	0.104	0.055	0.030	0.022
70	0	0	0	0.012	0.200	0.306	0.180	0.076	0.030	0.013	0.006	0.006
65	0	0	0	0.079	0.322	0.200	0.065	0.018	0.005	0.002	0.001	0.001
60	0	0	0.004	0.244	0.265	0.072	0.013	0.003	0.001	0	0	0
55	0	0	0.046	0.350	0.112	0.014	0.002	0	0	0	0	0
50	0	0	0.210	0.232	0.024	0.002	0	0	0	0	0	0
45	0	0.003	0.381	0.071	0.003	0	0	0	0	0	0	0
42	0	0.019	0.191	0.009	0	0	0	0	0	0	0	0
39	0	0.072	0.109	0.002	0	0	0	0	0	0	0	0
36	0	0.172	0.044	0	0	0	0	0	0	0	0	0
33	0	0.261	0.012	0	0	0	0	0	0	0	0	0
30	0	0.249	0.002	0	0	0	0	0	0	0	0	0
27	0.002	0.150	0	0	0	0	0	0	0	0	0	0
24	0.016	0.057	0	0	0	0	0	0	0	0	0	0
21	0.088	0.014	0	0	0	0	0	0	0	0	0	0
18	0.238	0.002	0	0	0	0	0	0	0	0	0	0
15	0.329	0	0	0	0	0	0	0	0	0	0	0
12	0.230	0	0	0	0	0	0	0	0	0	0	0
9	0.098	0	0	0	0	0	0	0	0	0	0	0

Table 2.23–Schedules of Pacific cod weight (kg) and maturity proportions at length (cm) as defined by final parameter estimates. Lengths correspond to lower bounds of size bins.

Bin	Length	Weight	Maturity
1	9	0.010	0.000
2	12	0.021	0.001
3	15	0.040	0.001
4	18	0.068	0.001
5	21	0.107	0.002
6	24	0.160	0.003
7	27	0.229	0.004
8	30	0.317	0.006
9	33	0.425	0.010
10	36	0.556	0.015
11	39	0.713	0.023
12	42	0.898	0.035
13	45	1.201	0.061
14	50	1.659	0.117
15	55	2.225	0.210
16	60	2.912	0.347
17	65	3.735	0.514
18	70	4.705	0.678
19	75	5.838	0.808
20	80	7.146	0.894
21	85	8.645	0.945
22	90	10.348	0.972
23	95	12.271	0.986
24	100	14.428	0.993
25	105	15.566	0.995

Table 2.24–Schedules of Pacific cod selectivities as defined by final parameter estimates. Lengths (cm) correspond to lower bounds of size bins.

Bin	Len.	Trawl (Jan.-May)			Trawl (Jun.-Dec.)			Longline			Pot		Survey	
		78-88	89-99	00-02	78-88	89-99	00-02	78-88	89-99	00-02	89-99	00-02	78-81	82-02
1	9	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.116
2	12	0.001	0.002	0.000	0.000	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.023	0.198
3	15	0.004	0.004	0.001	0.001	0.001	0.003	0.000	0.000	0.000	0.000	0.000	0.062	0.281
4	18	0.007	0.008	0.002	0.002	0.003	0.005	0.000	0.000	0.000	0.000	0.000	0.126	0.363
5	21	0.013	0.013	0.003	0.004	0.005	0.011	0.000	0.000	0.000	0.000	0.000	0.222	0.446
6	24	0.022	0.022	0.005	0.006	0.009	0.019	0.001	0.001	0.001	0.000	0.000	0.354	0.528
7	27	0.036	0.036	0.007	0.010	0.016	0.035	0.001	0.001	0.002	0.001	0.000	0.510	0.611
8	30	0.058	0.056	0.011	0.017	0.028	0.061	0.003	0.003	0.004	0.001	0.001	0.667	0.693
9	33	0.092	0.087	0.017	0.028	0.050	0.104	0.006	0.006	0.009	0.002	0.001	0.799	0.776
10	36	0.142	0.131	0.026	0.046	0.086	0.172	0.013	0.014	0.021	0.005	0.003	0.897	0.858
11	39	0.213	0.192	0.039	0.075	0.144	0.270	0.027	0.030	0.047	0.012	0.008	0.961	0.941
12	42	0.305	0.274	0.058	0.118	0.231	0.397	0.054	0.065	0.103	0.027	0.020	0.999	0.979
13	45	0.416	0.373	0.085	0.181	0.350	0.540	0.107	0.134	0.211	0.059	0.049	0.880	0.903
14	50	0.616	0.561	0.155	0.339	0.588	0.755	0.290	0.370	0.523	0.194	0.196	0.698	0.779
15	55	0.784	0.735	0.266	0.545	0.790	0.892	0.583	0.694	0.818	0.483	0.539	0.557	0.661
16	60	0.893	0.860	0.417	0.741	0.909	0.958	0.829	0.902	0.949	0.790	0.852	0.462	0.553
17	65	0.953	0.935	0.587	0.878	0.964	0.986	0.946	0.981	0.987	0.946	0.969	0.405	0.455
18	70	0.982	0.975	0.740	0.954	0.986	0.998	0.986	0.957	0.997	0.997	0.998	0.372	0.370
19	75	0.996	0.995	0.853	0.992	0.995	0.863	0.999	0.799	1.000	0.870	0.719	0.353	0.298
20	80	0.933	0.916	0.924	0.913	0.998	0.676	0.827	0.666	0.645	0.742	0.527	0.343	0.237
21	85	0.721	0.805	0.965	0.864	1.000	0.587	0.640	0.570	0.612	0.653	0.473	0.338	0.186
22	90	0.569	0.745	0.987	0.859	0.973	0.554	0.495	0.507	0.612	0.601	0.460	0.335	0.145
23	95	0.512	0.719	0.999	0.859	0.925	0.544	0.396	0.469	0.612	0.573	0.458	0.333	0.112
24	100	0.496	0.709	1.000	0.859	0.878	0.540	0.334	0.446	0.612	0.558	0.457	0.333	0.086
25	105	0.493	0.707	1.000	0.859	0.850	0.540	0.309	0.438	0.612	0.553	0.457	0.332	0.073

Table 2.25–Time series of EBS Pacific cod age 3+ biomass, spawning biomass, and survey biomass as estimated in last year's and this year's assessments.

Year	Age 3+ Biomass		Spawning Biomass		Survey Biomass	
	Last Year	This Year	Last Year	This Year	Last Year	This Year
1978	323	320	48	48	n/a	n/a
1979	475	474	79	79	564	555
1980	1054	1053	135	136	918	917
1981	1566	1576	250	254	1058	1063
1982	2025	2052	426	435	1188	1206
1983	2345	2388	599	615	1114	1135
1984	2374	2429	714	736	1075	1090
1985	2528	2587	753	780	1105	1120
1986	2489	2553	755	783	1094	1105
1987	2566	2627	759	788	1118	1126
1988	2564	2621	755	784	1027	1033
1989	2415	2465	742	770	864	866
1990	2165	2209	715	739	711	709
1991	1892	1927	648	669	656	646
1992	1719	1736	549	565	712	694
1993	1691	1690	480	490	753	730
1994	1682	1669	467	473	778	749
1995	1725	1692	457	457	771	738
1996	1646	1601	444	439	691	657
1997	1524	1471	432	423	594	562
1998	1340	1282	403	390	575	545
1999	1324	1267	373	357	607	585
2000	1318	1270	355	339	598	594
2001	1273	1251	356	343	609	620
2002	n/a	1315	n/a	346	n/a	717

Notes: Spawning biomass is computed as the sum of March female numbers at age times population weight at age times fraction mature at age.

"Survey biomass" is the model's estimate of what the actual survey should have observed.

All biomass figures are in 1000s of t.

Table 2.26–Time series of EBS Pacific cod age 3 recruitment as estimated in last year's and this year's assessments.

Year	Recruitment (millions of age 3 fish)	
	Last Year	This Year
1978	92	92
1979	173	175
1980	696	698
1981	311	316
1982	353	362
1983	281	286
1984	91	93
1985	515	518
1986	153	157
1987	418	417
1988	257	255
1989	159	158
1990	91	91
1991	121	119
1992	292	283
1993	287	276
1994	167	162
1995	324	309
1996	159	153
1997	132	125
1998	125	120
1999	269	269
2000	174	177
2001	128	145
2002	n/a	275

Table 2.27–Time series of EBS Pacific cod catch divided by age 3+ biomass as estimated in last year's and this year's assessments (the entry for 2002 under "This Year" is based on catch through August, 2002; the entry for 2001 under "Last Year" was based on catch through August, 2001).

Year	EBS Catch Divided by Age 3+ Biomass	
	Last Year	This Year
1978	0.13	0.13
1979	0.07	0.07
1980	0.04	0.04
1981	0.04	0.04
1982	0.03	0.03
1983	0.04	0.04
1984	0.05	0.05
1985	0.06	0.06
1986	0.05	0.05
1987	0.06	0.06
1988	0.08	0.08
1989	0.07	0.07
1990	0.08	0.08
1991	0.11	0.11
1992	0.10	0.10
1993	0.08	0.08
1994	0.10	0.10
1995	0.13	0.14
1996	0.13	0.13
1997	0.15	0.16
1998	0.12	0.13
1999	0.11	0.12
2000	0.11	0.12
2001	0.07	0.11
2002	n/a	0.09

Table 2.28–Definitions of symbols and terms used in the Pacific cod projection tables.

Symbol	Definition
SPR	Equilibrium spawning per recruit, expressed as a percentage of the maximum level
L90%CI	Lower bound of the 90% confidence interval
Median	Point that divides projection outputs into two groups of equal size (50% higher, 50% lower)
Mean	Average value of the projection outputs
U90%CI	Upper bound of the 90% confidence interval
St. Dev.	Standard deviation of the projection outputs

Table 2.29–Equilibrium reference points and projections for BSAI Pacific cod spawning biomass (1000s of t), fishing mortality, and catch (1000s of t) under the assumption that $F = max\ F_{ABC}$ in each year 2003-2015, where future recruitment is drawn from a distribution based on estimated recruitments spawned during the period 1977-2001. See Table 2.28 for symbol definitions.

Equilibrium Reference Points

SPR	Spawning Biomass	Fishing Mortality	Catch
100%	1,076	0	0
40%	431	0.35	286
35%	377	0.42	305

Spawning Biomass Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2003	424.3	424.3	424.3	424.3	0.00
2004	425.8	426.0	426.1	426.6	0.25
2005	430.3	433.9	434.7	442.2	3.93
2006	398.4	417.5	422.2	461.6	21.10
2007	358.4	404.5	413.8	499.0	46.91
2008	336.5	405.7	418.1	537.3	65.55
2009	329.6	412.6	426.0	561.3	75.26
2010	332.7	419.5	433.0	572.7	79.39
2011	333.7	423.9	437.7	587.5	80.49
2012	336.5	426.3	440.0	599.5	81.03
2013	339.2	424.3	441.2	593.5	81.71
2014	337.1	426.5	442.7	585.5	81.86
2015	340.7	427.6	443.6	600.3	81.20

Fishing Mortality Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2003	0.35	0.35	0.35	0.35	0.000
2004	0.35	0.35	0.35	0.35	0.000
2005	0.35	0.35	0.35	0.35	0.000
2006	0.32	0.34	0.34	0.35	0.010
2007	0.29	0.33	0.33	0.35	0.022
2008	0.27	0.33	0.32	0.35	0.028
2009	0.26	0.34	0.32	0.35	0.030
2010	0.27	0.34	0.33	0.35	0.030
2011	0.27	0.35	0.33	0.35	0.030
2012	0.27	0.35	0.33	0.35	0.029
2013	0.27	0.35	0.33	0.35	0.029
2014	0.27	0.35	0.33	0.35	0.028
2015	0.27	0.35	0.33	0.35	0.028

Catch Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2003	277.9	277.9	277.9	277.9	0.00
2004	295.9	296.2	296.2	296.8	0.28
2005	292.6	296.7	297.7	306.3	4.47
2006	236.2	269.3	275.0	329.9	30.98
2007	188.5	257.1	264.2	360.9	56.55
2008	170.3	262.0	268.5	387.5	69.47
2009	165.5	272.3	275.5	395.5	74.54
2010	168.6	278.2	281.0	401.0	75.47
2011	167.2	284.9	284.1	413.6	75.30
2012	172.5	283.9	285.5	416.2	75.37
2013	174.2	287.2	286.9	410.7	75.35
2014	172.5	287.0	288.0	411.0	74.76
2015	176.2	286.1	289.1	417.0	74.20

Table 2.30–Equilibrium reference points and projections for BSAI Pacific cod spawning biomass (1000s of t), fishing mortality, and catch (1000s of t) under the assumption that the ratio of F to $max\ F_{ABC}$ in each year 2003-2015 is fixed at a value of 0.87, where future recruitment is drawn from a distribution based on estimated recruitments spawned during the period 1977-2001. See Table 2.28 for symbol definitions.

Equilibrium Reference Points

SPR	Spawning Biomass	Fishing Mortality	Catch
100%	1,076	0	0
40%	431	0.35	286
35%	377	0.42	305

Spawning Biomass Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2003	426.6	426.6	426.6	426.6	0.00
2004	439.5	439.7	439.8	440.3	0.26
2005	453.0	456.5	457.4	465.1	3.99
2006	427.3	447.2	452.0	492.3	21.68
2007	384.9	434.4	444.8	535.7	50.28
2008	359.6	435.8	448.7	581.1	71.72
2009	350.6	442.1	456.9	608.6	83.30
2010	350.9	448.5	464.5	619.8	88.43
2011	355.1	454.6	470.3	637.2	90.01
2012	356.8	460.1	473.5	650.0	90.77
2013	359.4	458.1	475.2	644.7	91.48
2014	359.3	461.2	477.3	641.3	91.57
2015	362.0	464.0	478.5	649.4	90.89

Fishing Mortality Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2003	0.30	0.30	0.30	0.30	0.000
2004	0.31	0.31	0.31	0.31	0.000
2005	0.31	0.31	0.31	0.31	0.000
2006	0.30	0.31	0.31	0.31	0.002
2007	0.27	0.31	0.30	0.31	0.013
2008	0.25	0.31	0.29	0.31	0.019
2009	0.24	0.31	0.29	0.31	0.021
2010	0.25	0.31	0.29	0.31	0.021
2011	0.25	0.31	0.29	0.31	0.021
2012	0.25	0.31	0.29	0.31	0.021
2013	0.25	0.31	0.29	0.31	0.020
2014	0.25	0.31	0.29	0.31	0.019
2015	0.25	0.31	0.30	0.31	0.019

Catch Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2003	245.1	245.1	245.1	245.1	0.00
2004	269.8	269.9	269.9	270.1	0.10
2005	268.9	272.4	273.3	280.8	3.90
2006	235.1	258.6	263.1	305.1	22.84
2007	187.8	253.8	254.7	335.1	47.45
2008	167.6	256.0	257.0	362.9	60.71
2009	161.8	262.1	262.1	368.4	65.96
2010	164.3	265.3	266.8	371.8	67.21
2011	162.1	270.4	269.9	389.7	67.14
2012	168.6	269.1	271.5	388.5	67.25
2013	171.0	271.7	272.9	384.5	67.20
2014	169.4	272.8	274.2	384.1	66.55
2015	172.2	272.4	275.3	390.7	65.92

Table 2.31–Equilibrium reference points and projections for BSAI Pacific cod spawning biomass (1000s of t), fishing mortality, and catch (1000s of t) under the assumption that F = ½ *max* F_{ABC} in each year 2003-2015, where future recruitment is drawn from a distribution based on estimated recruitments spawned during the period 1977-2001. See Table 2.28 for symbol definitions.

Equilibrium Reference Points

SPR	Spawning Biomass	Fishing Mortality	Catch
100%	1,076	0	0
40%	431	0.35	286
35%	377	0.42	305

Spawning Biomass Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2003	433.3	433.3	433.3	433.3	0.00
2004	482.1	482.3	482.3	482.8	0.26
2005	529.5	533.1	534.0	541.7	4.00
2006	532.2	552.7	557.6	598.7	22.14
2007	502.1	557.6	568.4	666.8	54.38
2008	473.2	568.6	581.4	730.3	84.05
2009	457.7	578.9	594.8	779.1	103.92
2010	451.2	590.5	606.6	802.9	114.89
2011	447.3	603.2	616.3	826.0	119.91
2012	449.9	609.2	622.8	846.6	122.29
2013	452.0	612.7	626.3	847.0	123.46
2014	459.9	615.8	630.3	843.7	123.54
2015	461.8	617.6	633.2	848.1	122.57

Fishing Mortality Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2003	0.17	0.17	0.17	0.17	0.000
2004	0.18	0.18	0.18	0.18	0.000
2005	0.18	0.18	0.18	0.18	0.000
2006	0.18	0.18	0.18	0.18	0.000
2007	0.18	0.18	0.18	0.18	0.000
2008	0.18	0.18	0.18	0.18	0.000
2009	0.18	0.18	0.18	0.18	0.002
2010	0.18	0.18	0.18	0.18	0.002
2011	0.18	0.18	0.18	0.18	0.003
2012	0.18	0.18	0.18	0.18	0.003
2013	0.18	0.18	0.18	0.18	0.003
2014	0.18	0.18	0.18	0.18	0.003
2015	0.18	0.18	0.18	0.18	0.003

Catch Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2003	146.6	146.6	146.6	146.6	0.00
2004	172.3	172.3	172.3	172.4	0.06
2005	182.3	184.3	184.8	189.2	2.25
2006	171.5	183.7	186.6	211.3	13.28
2007	157.2	184.9	189.1	236.2	25.76
2008	149.1	188.7	194.1	257.3	34.39
2009	145.5	193.5	198.5	266.0	39.24
2010	145.2	196.8	201.9	272.5	41.47
2011	145.4	200.2	204.3	282.4	42.35
2012	146.8	201.6	205.9	285.1	42.92
2013	149.0	201.3	207.0	280.3	43.04
2014	149.3	202.9	208.1	281.8	42.86
2015	150.7	203.9	209.0	285.7	42.40

Table 2.32–Equilibrium reference points and projections for BSAI Pacific cod spawning biomass (1000s of t), fishing mortality, and catch (1000s of t) under the assumption that *F* = the 1997-2001 average in each year 2003-2015, where future recruitment is drawn from a distribution based on estimated recruitments spawned during the period 1977-2001. See Table 2.28 for symbol definitions.

Equilibrium Reference Points

SPR	Spawning Biomass	Fishing Mortality	Catch
100%	1,076	0	0
40%	431	0.35	286
35%	377	0.42	305

Spawning Biomass Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2003	431.9	431.9	431.9	431.9	0.00
2004	472.9	473.1	473.2	473.7	0.26
2005	513.4	517.0	517.9	525.5	4.00
2006	509.9	530.3	535.2	576.1	22.06
2007	476.2	530.9	541.7	638.8	53.71
2008	445.9	539.8	551.8	697.3	82.16
2009	430.4	547.9	563.1	742.8	100.73
2010	422.7	558.1	573.3	760.9	110.73
2011	419.9	569.0	581.6	785.2	115.19
2012	423.1	575.0	587.1	802.1	117.28
2013	422.2	578.5	590.1	802.2	118.30
2014	431.5	578.8	593.5	796.8	118.30
2015	432.6	582.4	596.0	802.3	117.32

Fishing Mortality Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2003	0.20	0.20	0.20	0.20	0.000
2004	0.20	0.20	0.20	0.20	0.000
2005	0.20	0.20	0.20	0.20	0.000
2006	0.20	0.20	0.20	0.20	0.000
2007	0.20	0.20	0.20	0.20	0.000
2008	0.20	0.20	0.20	0.20	0.000
2009	0.20	0.20	0.20	0.20	0.000
2010	0.20	0.20	0.20	0.20	0.000
2011	0.20	0.20	0.20	0.20	0.000
2012	0.20	0.20	0.20	0.20	0.000
2013	0.20	0.20	0.20	0.20	0.000
2014	0.20	0.20	0.20	0.20	0.000
2015	0.20	0.20	0.20	0.20	0.000

Catch Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2003	168.0	168.0	168.0	168.0	0.00
2004	191.9	192.0	192.0	192.1	0.07
2005	200.9	203.1	203.7	208.7	2.56
2006	186.8	200.6	203.9	231.8	15.02
2007	169.8	200.9	205.6	258.1	28.87
2008	160.6	204.5	210.5	280.9	38.15
2009	156.4	209.3	215.1	289.3	43.06
2010	156.3	212.5	218.6	294.9	45.11
2011	155.9	216.4	220.9	306.3	45.83
2012	157.9	216.5	222.4	309.9	46.44
2013	160.4	217.1	223.5	305.0	46.62
2014	160.0	218.7	224.5	305.3	46.43
2015	161.3	219.4	225.4	311.5	45.92

Table 2.33–Equilibrium reference points and projections for BSAI Pacific cod spawning biomass (1000s of t), fishing mortality, and catch (1000s of t) under the assumption that $F = 0$ in each year 2003-2015, where future recruitment is drawn from a distribution based on estimated recruitments spawned during the period 1977-2001. See Table 2.28 for symbol definitions.

Equilibrium Reference Points

SPR	Spawning Biomass	Fishing Mortality	Catch
100%	1,076	0	0
40%	431	0.35	286
35%	377	0.42	305

Spawning Biomass Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2003	442.5	442.5	442.5	442.5	0.00
2004	547.3	547.6	547.6	548.1	0.26
2005	658.6	662.2	663.1	670.8	4.02
2006	726.1	747.1	752.1	794.3	22.72
2007	745.1	805.7	817.3	925.4	59.55
2008	744.7	857.1	872.5	1050.4	99.70
2009	742.7	898.3	918.6	1150.3	132.48
2010	746.8	934.5	956.7	1219.5	155.11
2011	750.1	967.4	988.4	1280.0	169.11
2012	756.4	994.3	1012.3	1334.4	177.63
2013	764.7	1006.4	1025.9	1358.2	182.66
2014	779.8	1019.7	1039.6	1371.5	185.11
2015	792.0	1034.6	1049.6	1367.7	185.10

Fishing Mortality Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2003	0	0	0	0	0
2004	0	0	0	0	0
2005	0	0	0	0	0
2006	0	0	0	0	0
2007	0	0	0	0	0
2008	0	0	0	0	0
2009	0	0	0	0	0
2010	0	0	0	0	0
2011	0	0	0	0	0
2012	0	0	0	0	0
2013	0	0	0	0	0
2014	0	0	0	0	0
2015	0	0	0	0	0

Catch Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2003	0	0	0	0	0
2004	0	0	0	0	0
2005	0	0	0	0	0
2006	0	0	0	0	0
2007	0	0	0	0	0
2008	0	0	0	0	0
2009	0	0	0	0	0
2010	0	0	0	0	0
2011	0	0	0	0	0
2012	0	0	0	0	0
2013	0	0	0	0	0
2014	0	0	0	0	0
2015	0	0	0	0	0

Table 2.34–Equilibrium reference points and projections for BSAI Pacific cod spawning biomass (1000s of t), fishing mortality, and catch (1000s of t) under the assumption that $F = F_{OFL}$ in each year 2003-2015, where future recruitment is drawn from a distribution based on estimated recruitments spawned during the period 1977-2001. See Table 2.28 for symbol definitions.

Equilibrium Reference Points

SPR	Spawning Biomass	Fishing Mortality	Catch
100%	1,076	0	0
40%	431	0.35	286
35%	377	0.42	305

Spawning Biomass Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2003	420.9	420.9	420.9	420.9	0.00
2004	407.2	407.4	407.4	407.9	0.25
2005	403.4	406.7	407.5	414.7	3.73
2006	367.9	385.9	390.4	426.3	19.61
2007	329.2	373.5	381.3	458.7	42.71
2008	310.3	375.3	385.1	489.1	58.20
2009	305.8	382.4	391.9	505.9	65.59
2010	308.5	385.7	397.1	513.7	68.35
2011	308.5	392.4	400.3	527.4	68.64
2012	312.7	390.1	401.3	531.8	68.81
2013	313.4	391.8	401.9	530.4	69.31
2014	312.4	390.3	403.0	526.7	69.46
2015	313.5	391.1	403.6	533.6	68.70

Fishing Mortality Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2003	0.41	0.41	0.41	0.41	0.000
2004	0.40	0.40	0.40	0.40	0.000
2005	0.39	0.40	0.40	0.41	0.004
2006	0.36	0.38	0.38	0.42	0.018
2007	0.32	0.36	0.37	0.42	0.033
2008	0.30	0.36	0.37	0.42	0.041
2009	0.29	0.37	0.37	0.42	0.044
2010	0.30	0.38	0.37	0.42	0.043
2011	0.30	0.38	0.37	0.42	0.044
2012	0.30	0.38	0.38	0.42	0.043
2013	0.30	0.38	0.38	0.42	0.042
2014	0.30	0.38	0.38	0.42	0.042
2015	0.30	0.38	0.38	0.42	0.042

Catch Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2003	324.3	324.3	324.3	324.3	0.00
2004	323.1	323.4	323.5	324.1	0.31
2005	307.5	314.3	316.1	331.0	7.75
2006	241.4	276.7	285.7	363.4	39.13
2007	191.3	264.7	276.3	398.0	67.45
2008	174.8	271.6	283.3	427.6	80.80
2009	171.3	281.1	292.0	435.9	85.95
2010	173.8	285.4	297.4	442.9	86.75
2011	173.8	294.0	300.4	450.2	86.36
2012	177.0	288.8	300.9	453.5	86.47
2013	178.9	293.1	301.9	450.8	86.46
2014	177.8	292.8	303.0	448.4	86.14
2015	180.7	292.1	304.1	449.4	85.65

Table 2.35–Equilibrium reference points and projections for BSAI Pacific cod spawning biomass (1000s of t), fishing mortality, and catch (1000s of t) under the assumption that $F = max\ F_{ABC}$ in each year 2003-2004 and $F = F_{OFL}$ thereafter, where future recruitment is drawn from a distribution based on estimated recruitments spawned during the period 1977-2001. See Table 2.28 for symbol definitions.

Equilibrium Reference Points

SPR	Spawning Biomass	Fishing Mortality	Catch
100%	1,076	0	0
40%	431	0.35	286
35%	377	0.42	305

Spawning Biomass Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2003	424.3	424.3	424.3	424.3	0.00
2004	425.8	426.0	426.1	426.6	0.25
2005	426.8	430.1	431.0	438.5	3.88
2006	378.7	396.6	401.4	439.1	20.31
2007	333.6	377.6	385.6	462.9	43.33
2008	311.8	376.5	386.5	492.2	58.58
2009	306.1	382.4	392.1	507.6	65.77
2010	308.3	385.5	397.0	514.2	68.41
2011	308.3	392.3	400.1	527.3	68.65
2012	312.6	390.0	401.2	532.0	68.81
2013	313.3	391.7	401.8	530.4	69.31
2014	312.4	390.3	403.0	526.7	69.46
2015	313.5	391.1	403.6	533.6	68.70

Fishing Mortality Projections

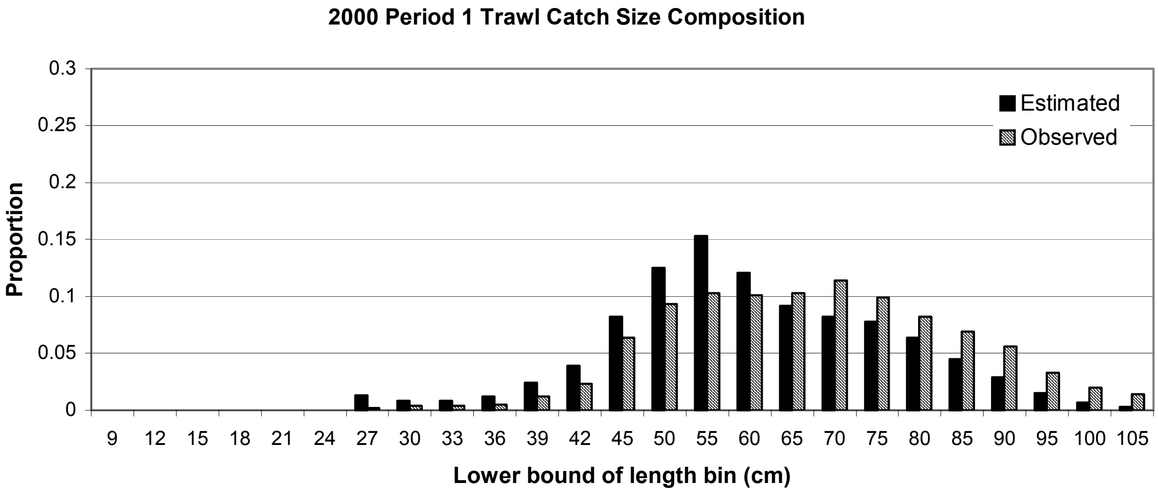
Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2003	0.35	0.35	0.35	0.35	0.000
2004	0.35	0.35	0.35	0.35	0.000
2005	0.42	0.42	0.42	0.42	0.001
2006	0.37	0.39	0.39	0.42	0.016
2007	0.32	0.37	0.37	0.42	0.033
2008	0.30	0.37	0.37	0.42	0.041
2009	0.29	0.37	0.37	0.42	0.044
2010	0.30	0.38	0.37	0.42	0.043
2011	0.30	0.38	0.37	0.42	0.044
2012	0.30	0.38	0.38	0.42	0.043
2013	0.30	0.38	0.38	0.42	0.042
2014	0.30	0.38	0.38	0.42	0.042
2015	0.30	0.38	0.38	0.42	0.042

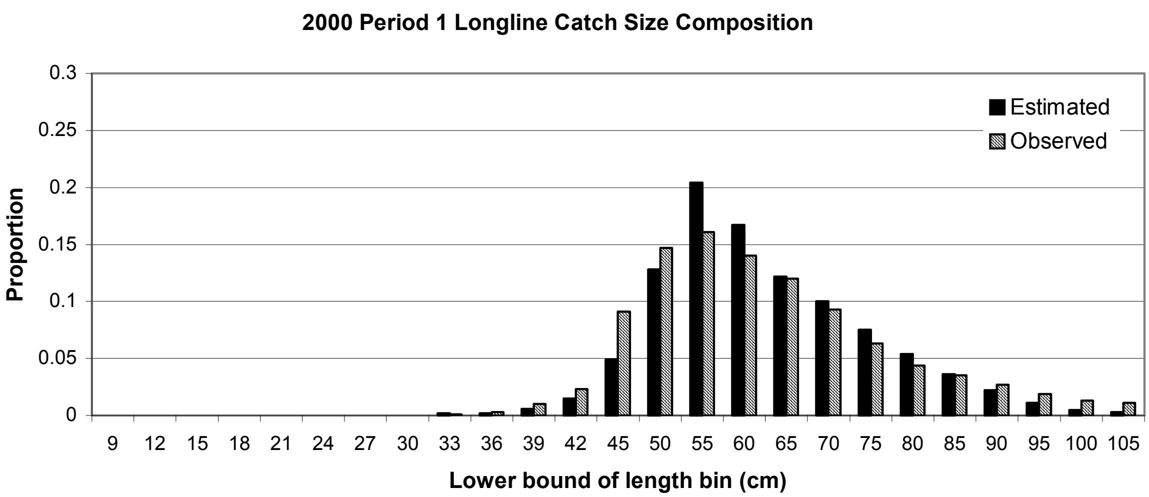
Catch Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2003	277.9	277.9	277.9	277.9	0.00
2004	295.9	296.2	296.2	296.8	0.28
2005	340.9	348.0	348.7	359.8	6.08
2006	254.0	290.0	299.2	374.7	39.11
2007	195.4	269.1	280.6	401.2	67.36
2008	176.0	272.7	284.4	428.1	80.80
2009	171.3	281.0	292.0	436.5	85.99
2010	173.6	285.1	297.2	442.7	86.80
2011	173.6	293.8	300.3	450.0	86.39
2012	176.9	288.7	300.8	453.5	86.48
2013	178.9	293.0	301.9	450.8	86.47
2014	177.8	292.8	303.0	448.4	86.14
2015	180.7	292.1	304.1	449.4	85.65

Table 2.36--Summary of major results for the stock assessment of Pacific cod in the BSAI region.

Natural mortality rate:		0.37
Reference fishing mortalities:	Rate	Value
	$F_{35\%}$	0.42
	$F_{40\%}$	0.35
	$max\ F_{ABC}$	0.35
Equilibrium spawning biomass:	Region and type	Value
	EBS $B_{35\%}$	322,000 t
	EBS $B_{40\%}$	368,000 t
	BSAI $B_{35\%}$	377,000 t
	BSAI $B_{40\%}$	431,000 t
Projected biomass for 2003:	Region and type	Value
	EBS Age 3+	1,440,000 t
	EBS Spawning (at $max\ F_{ABC}$)	362,000 t
	BSAI Age 3+	1,680,000 t
	BSAI Spawning (at $max\ F_{ABC}$)	423,000 t
Recommended ABC for 2003:	Units	Value
	Fishing Mortality	0.30
	EBS Catch	209,000 t
	BSAI Catch	245,000 t
Overfishing level for 2003:	Units	Value
	Fishing Mortality	0.41
	EBS Catch	277,000 t
	BSAI Catch	324,000 t





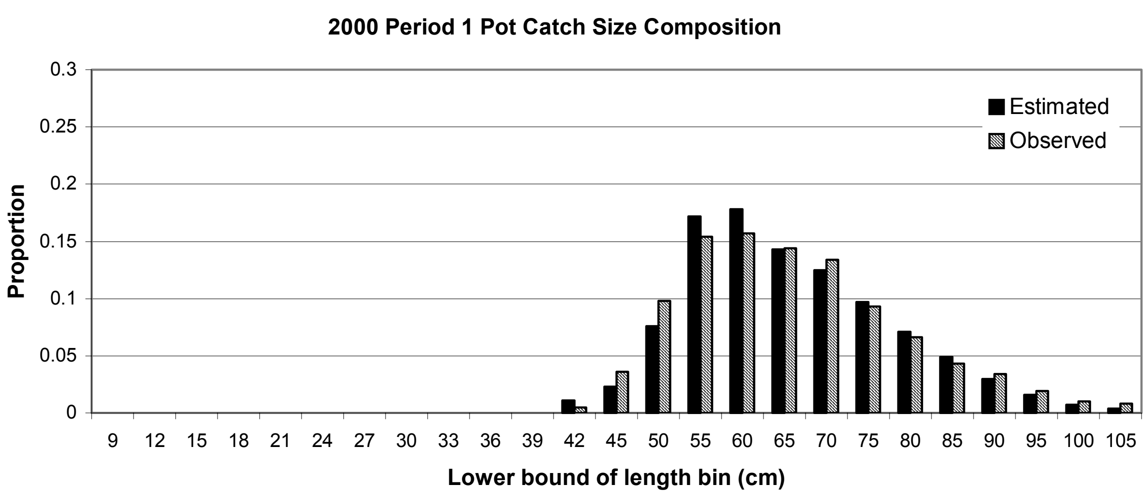


Figure 2.1–Estimated and observed size compositions from the 2000 period 1 fisheries (Model 1).

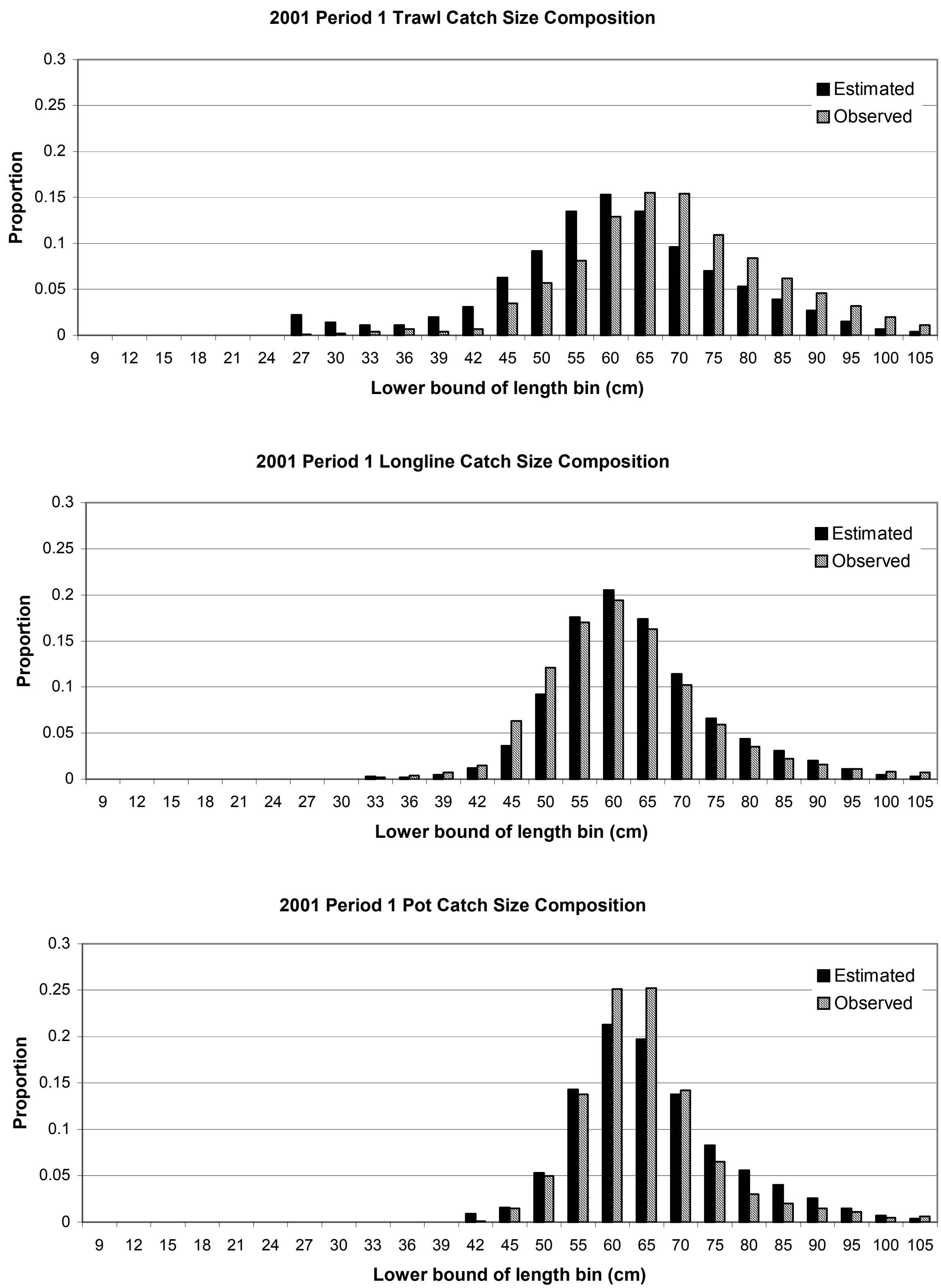
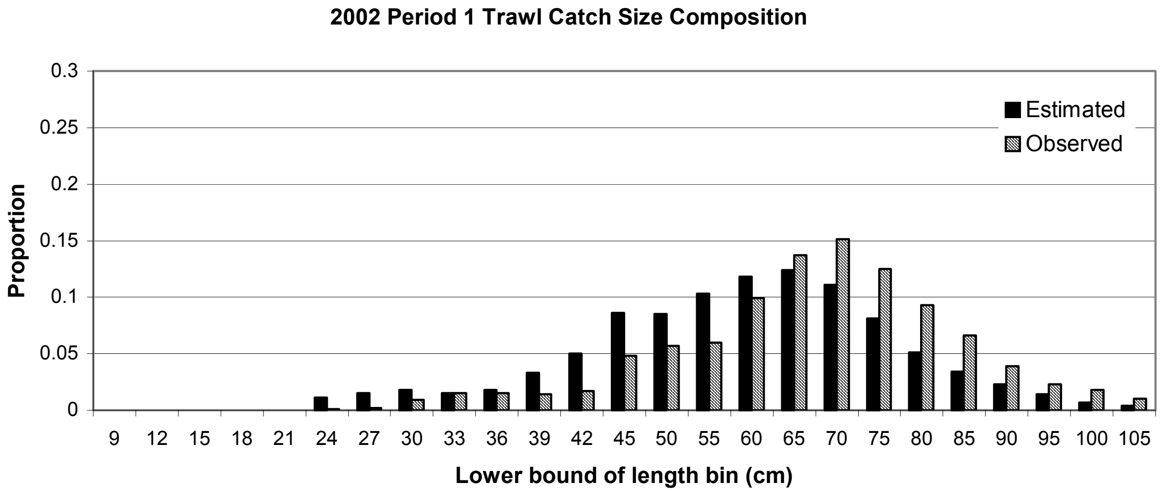
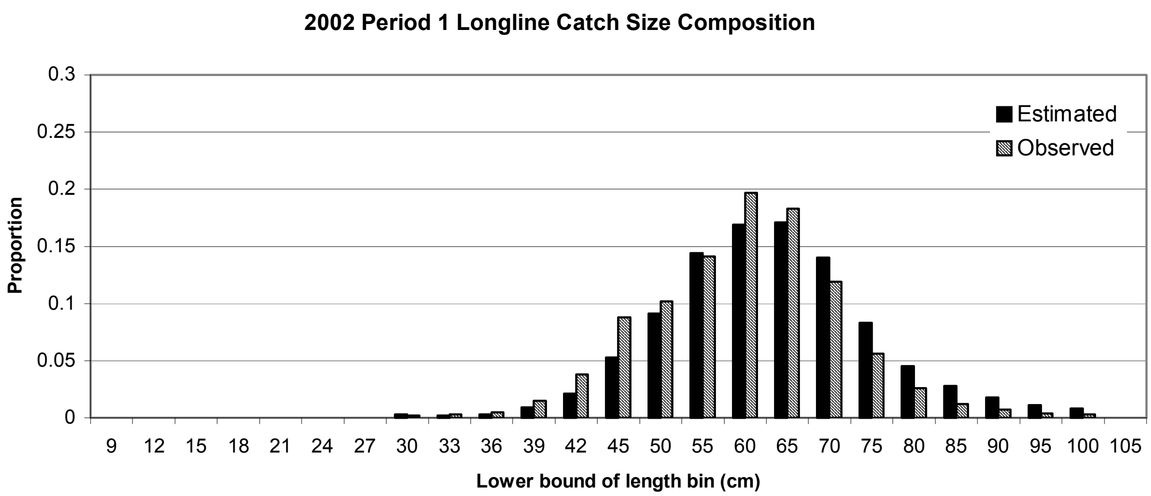


Figure 2.2–Estimated and observed size compositions from the 2001 period 1 fisheries (Model 1).





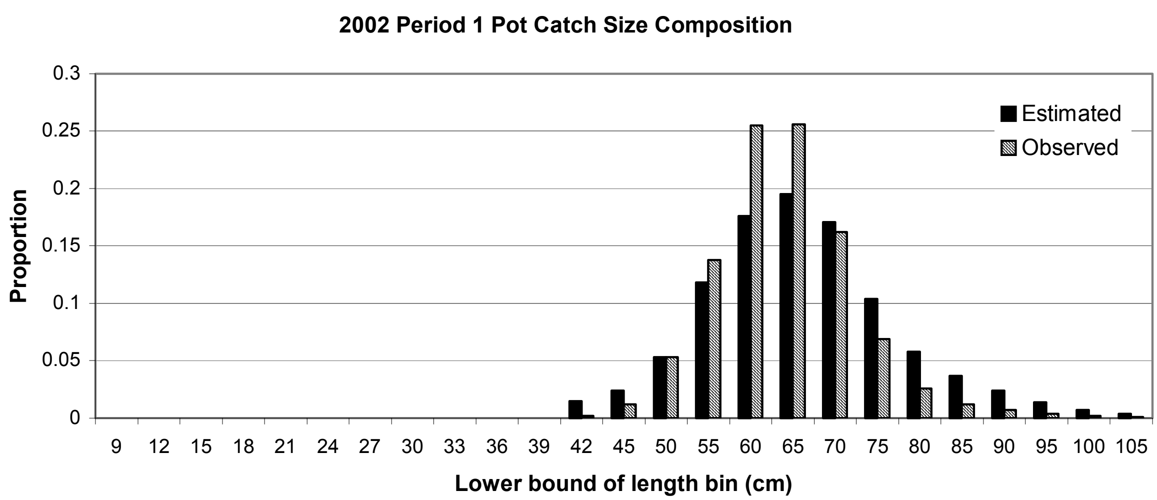


Figure 2.3–Estimated and observed size compositions from the 2002 period 1 fisheries (Model 1).

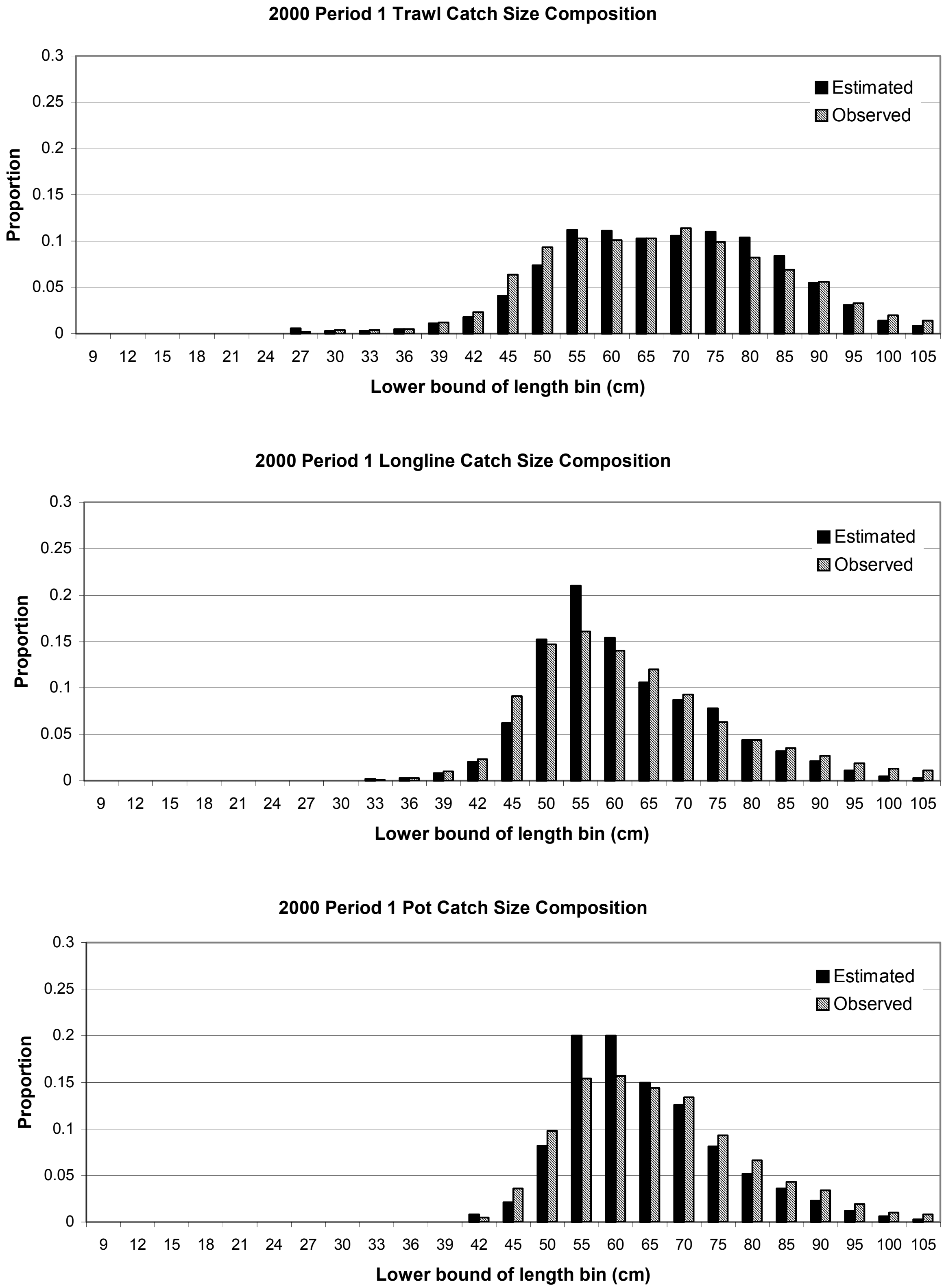
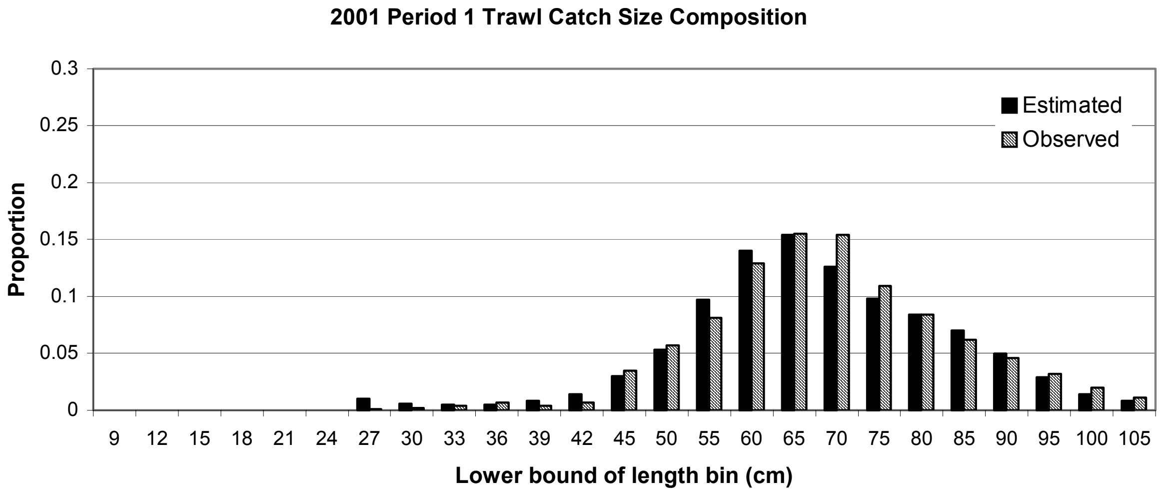
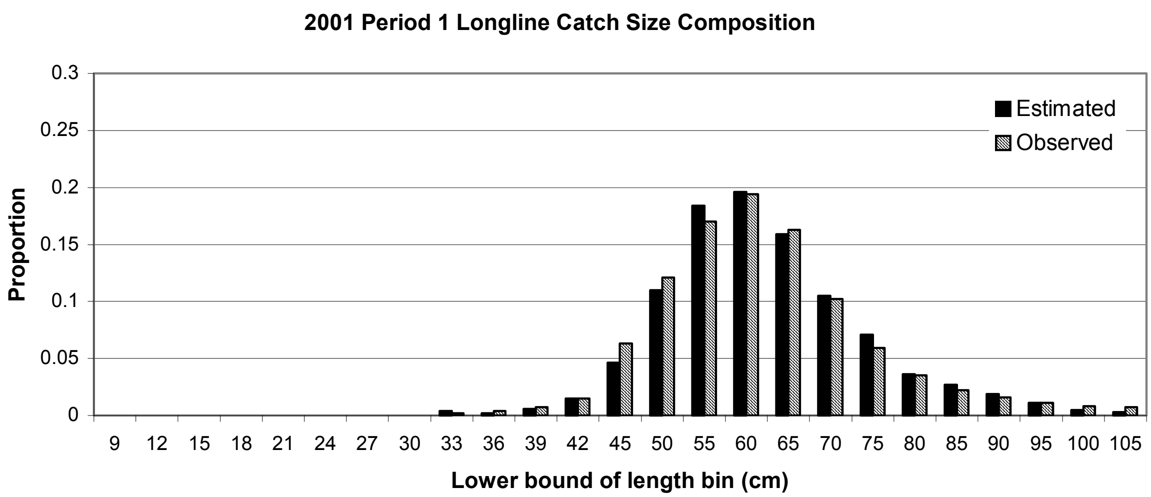


Figure 2.4–Estimated and observed size compositions from the 2000 period 1 fisheries (Model 2).





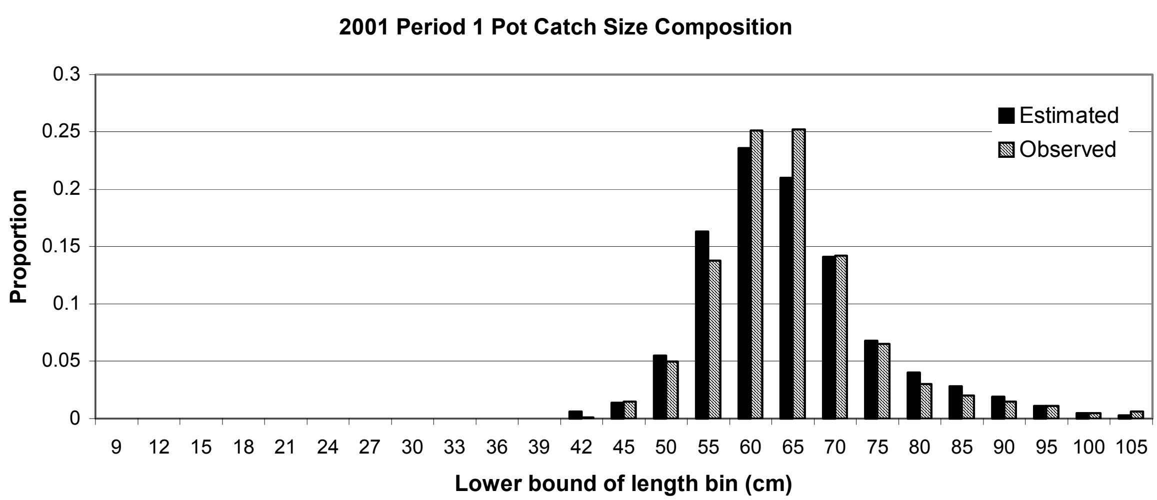


Figure 2.5–Estimated and observed size compositions from the 2001 period 1 fisheries (Model 2).

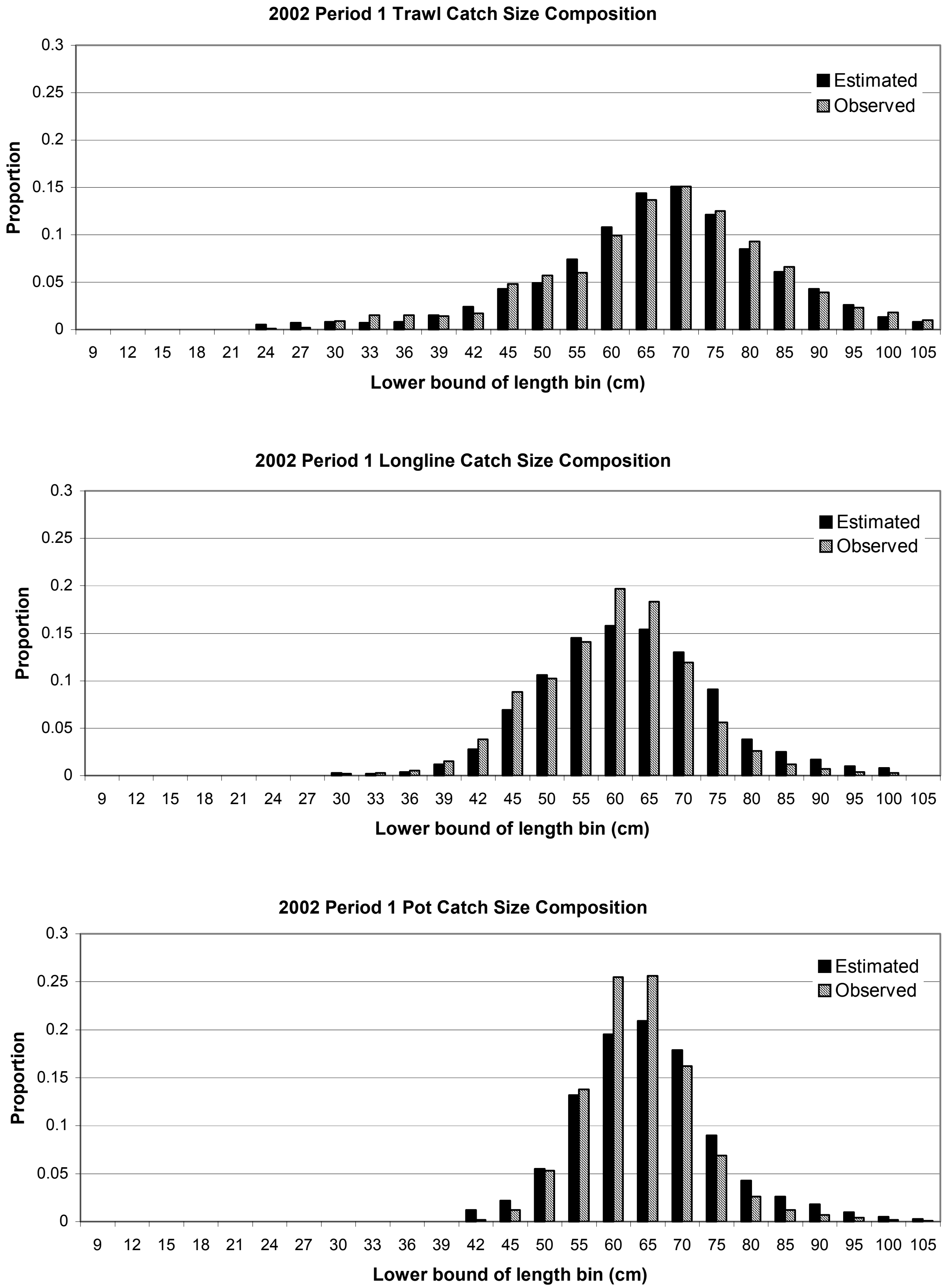
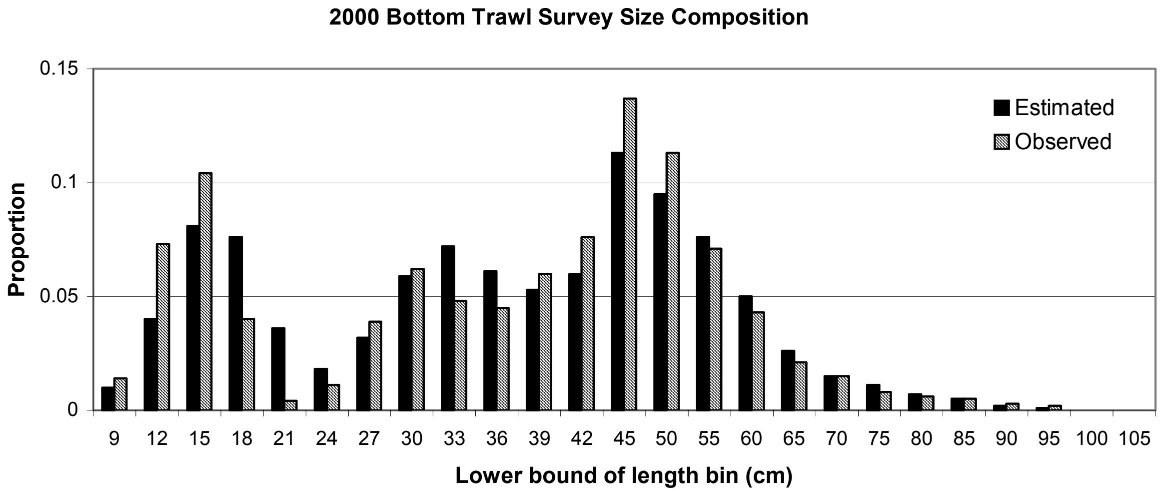
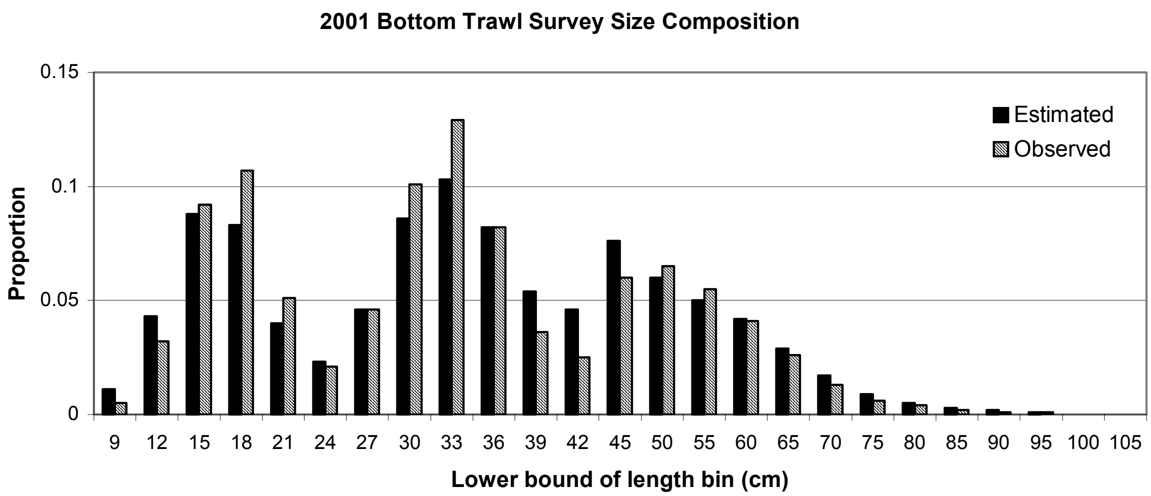


Figure 2.6–Estimated and observed size compositions from the 2002 period 1 fisheries (Model 2).





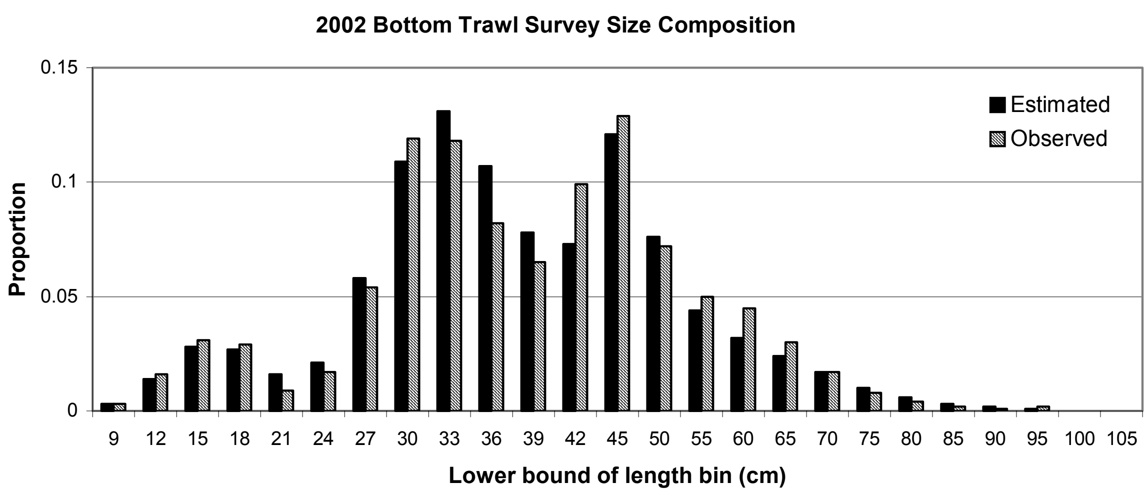
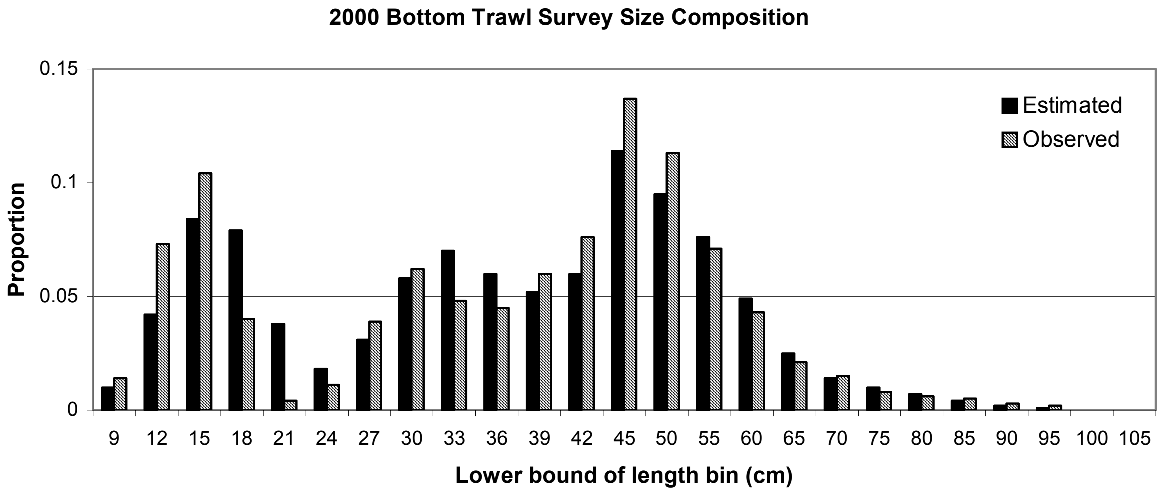
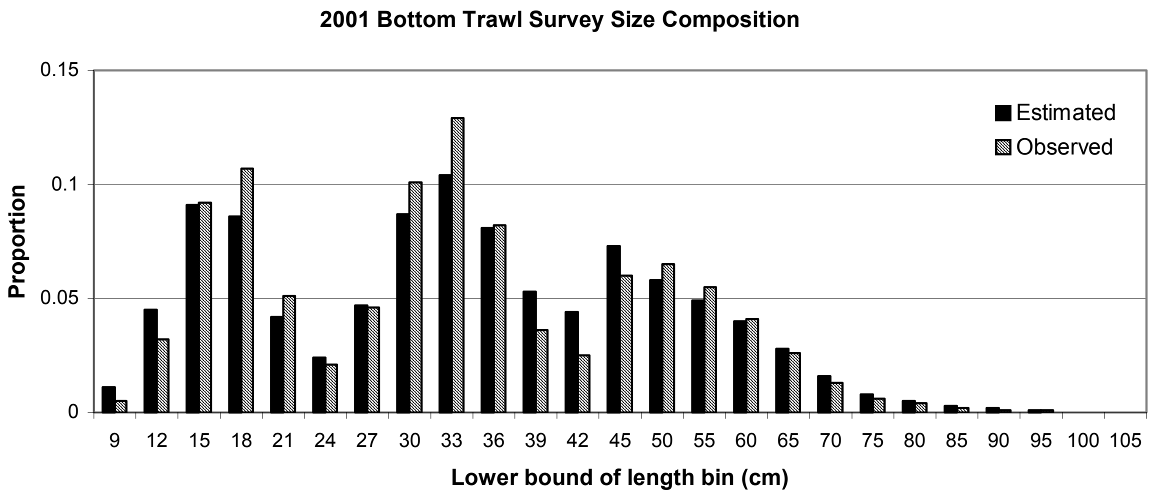


Figure 2.7–Estimated and observed size compositions from the 3 most recent surveys (Model 1).





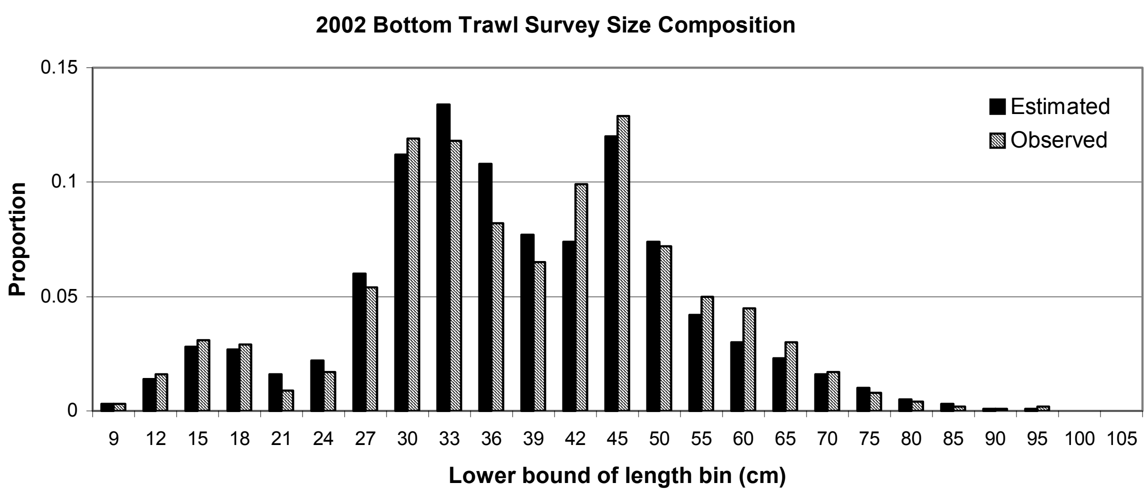


Figure 2.8–Estimated and observed size compositions from the 3 most recent surveys (Model 2).

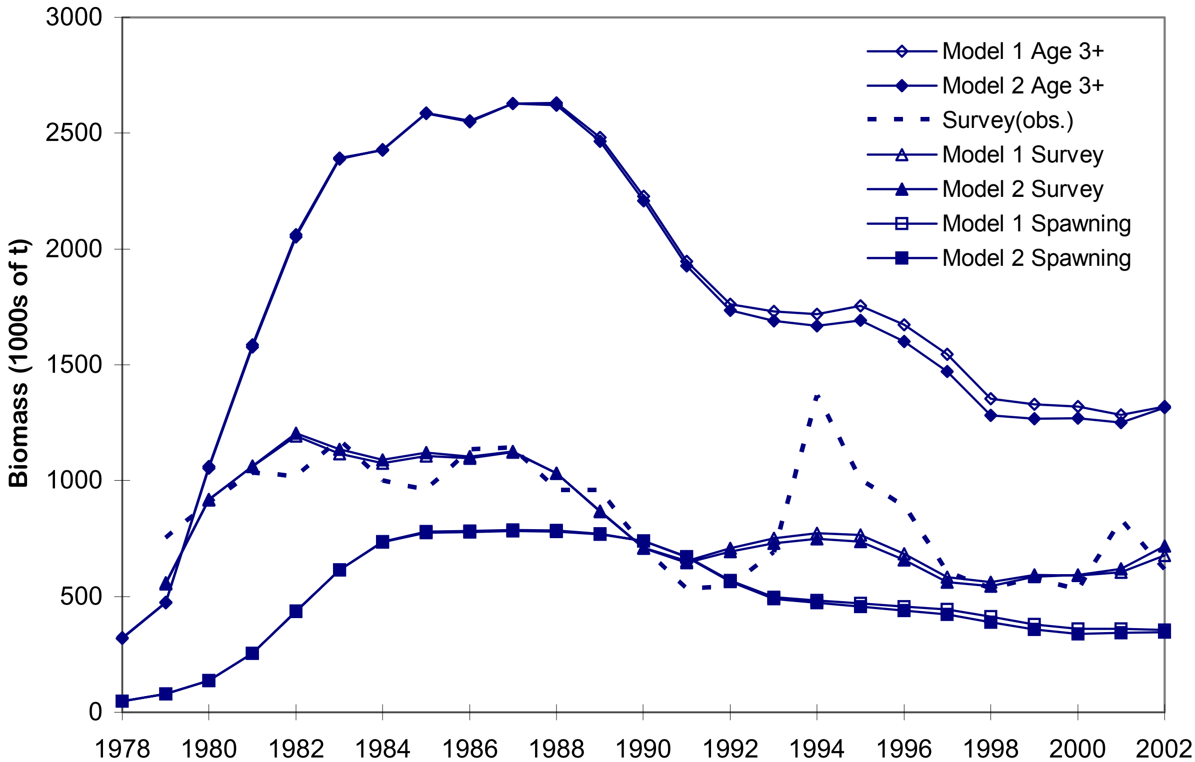


Figure 2.9–Comparison of biomass estimates resulting from Models 1 and 2.

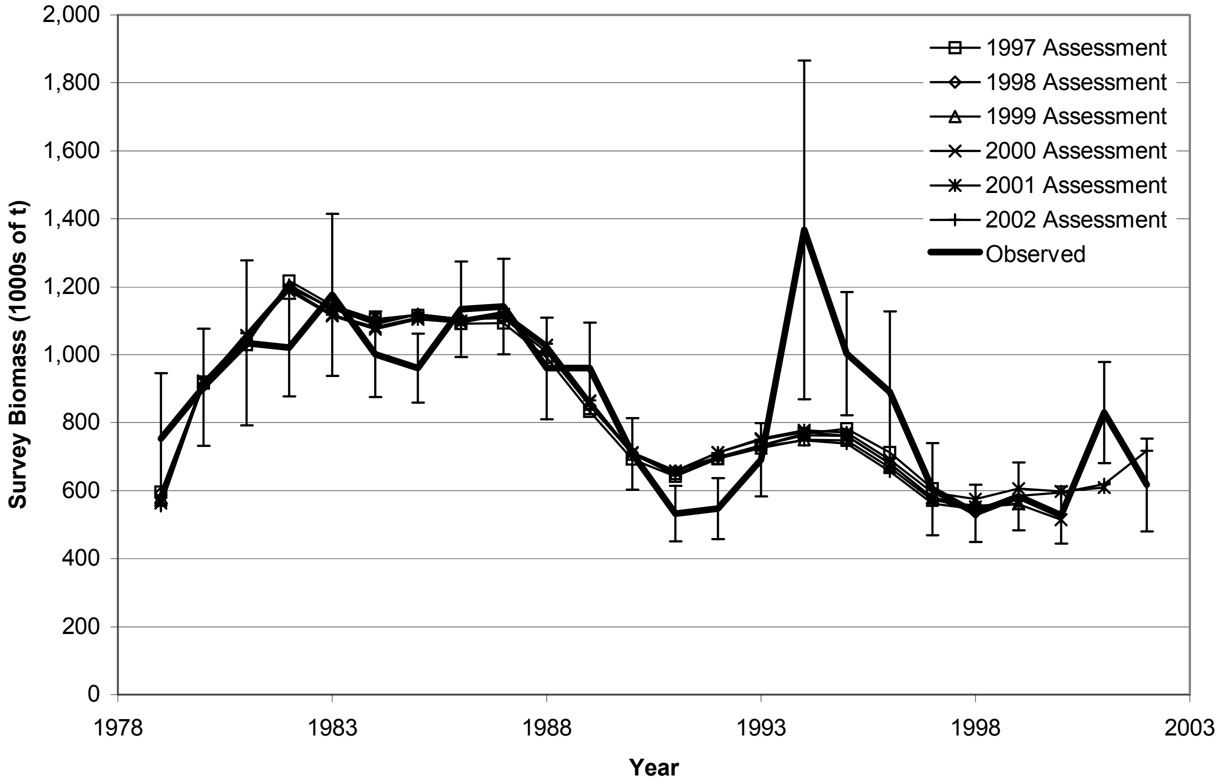


Figure 2.10–Retrospective analysis of estimated survey biomass, 1997-present. The vertical error bars around the observed survey biomass represent 1.96 standard deviations on either side of the mean.

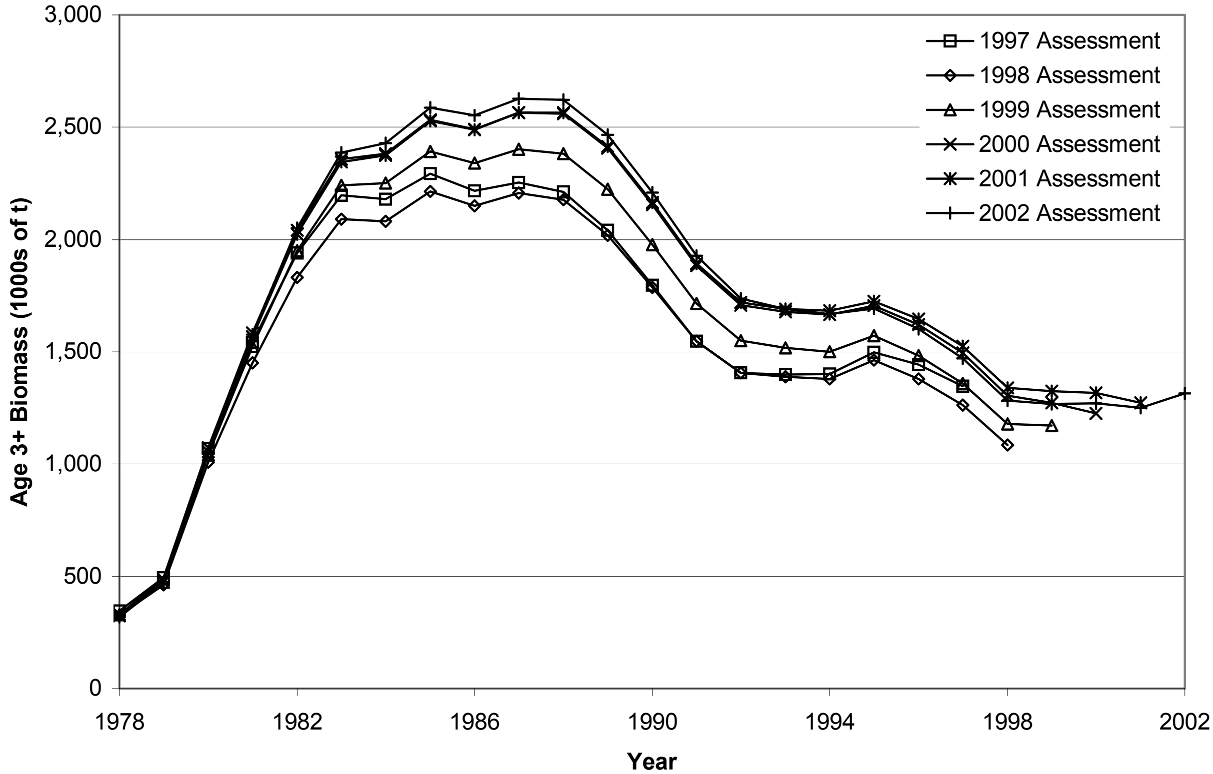


Figure 2.11–Retrospective analysis of estimated age 3+ biomass, 1997-present.

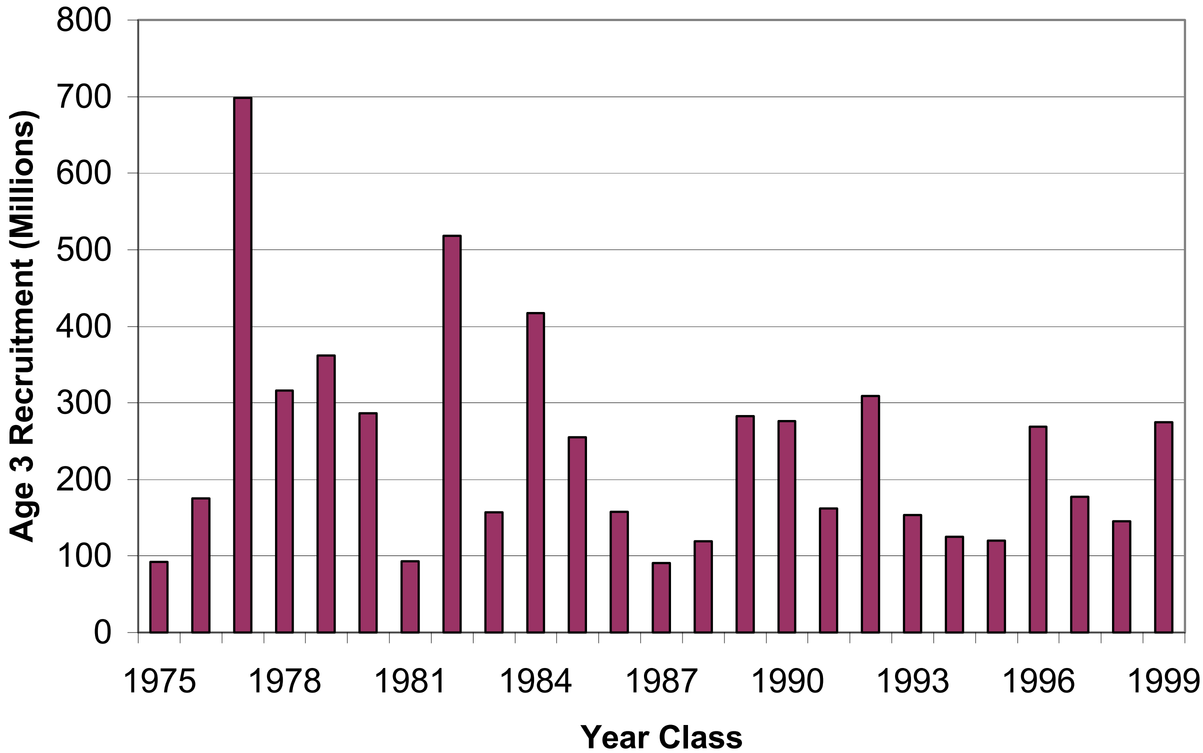


Figure 2.12–Pacific cod recruitment at age 3 (EBS only) as estimated by the stock assessment model.

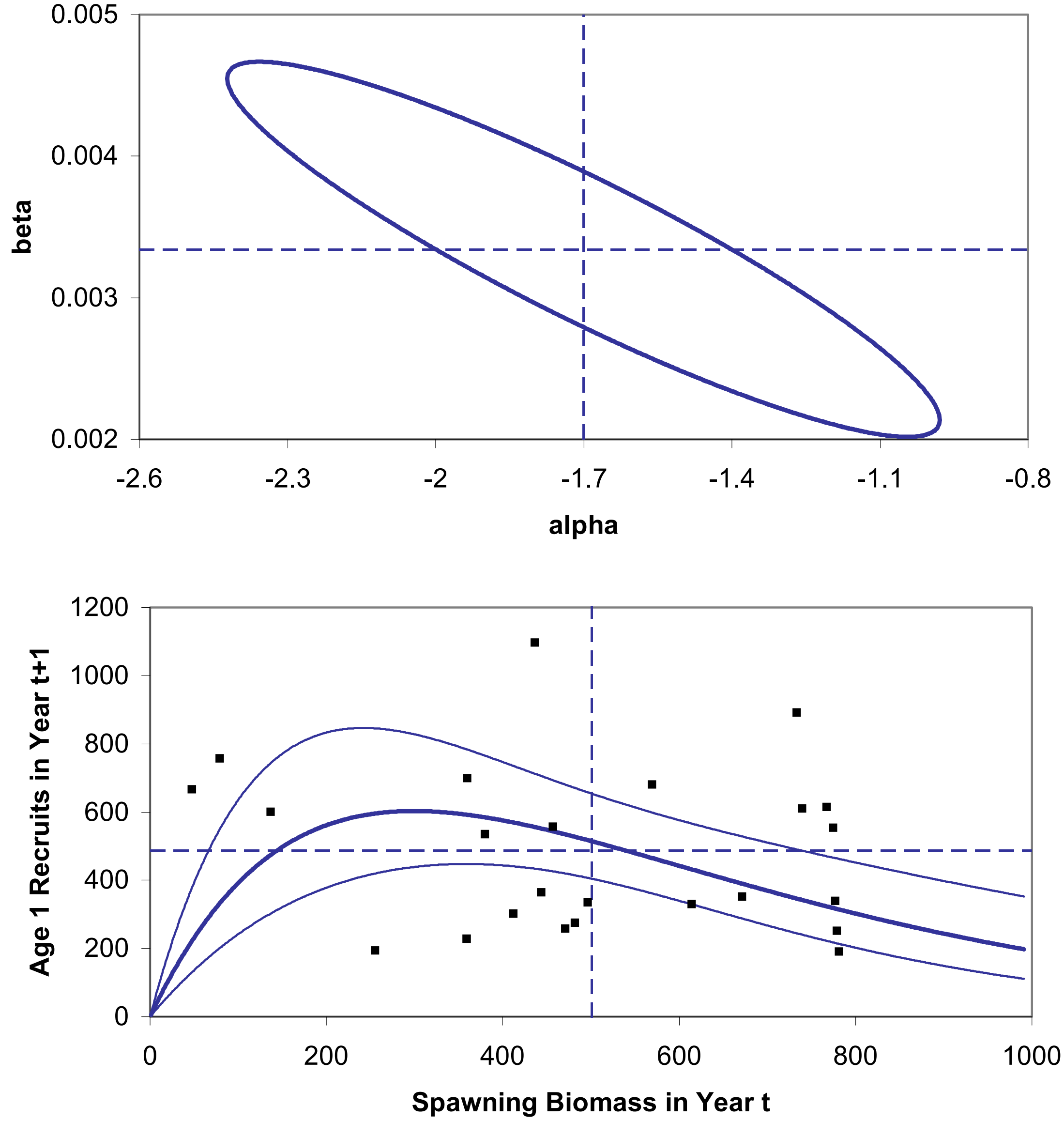


Figure 2.13–Some aspects of uncertainty surrounding the stock-recruitment relationship. The upper panel shows a 95% confidence ellipse for the estimated parameters of the stock-recruitment relationship, with dashed lines indicating the location of the point estimates. The lower panel shows the data (small squares), the estimated relationship (bold curve), and the 95% confidence interval around the curve (thin curves), with dashed lines indicating the locations of the data means. See text for details and caveats.

Appendix 2A: Approximate Functional Representations of Population Dynamics Used in Synthesis

These equations are similar to those used in Synthesis. Symbols are defined in Table 2.14.

Functions of Length or Age

Weight at length:

$$w(\lambda) = W_1 \lambda^{W_2}$$

Proportion mature at length:

$$p(\lambda) = \frac{1}{1 + \exp\left(- P_1 (P_2 - \lambda)\right)}$$

Length at age:

$$l(\alpha) = L_1 + (L_2 - L_1)\left(\frac{1 - \exp\left(- K(\alpha - \alpha_1)\right)}{1 - \exp\left(- K(\alpha_2 - \alpha_1)\right)}\right)$$

Standard deviation of length at age:

$$x(\alpha) = X_1 + (X_2 - X_1)\left(\frac{l(\alpha) - L_1}{L_2 - L_1}\right)$$

Probability density function describing distribution of length, conditional on age:

$$h(\lambda \mid \alpha) = \sqrt{\frac{1}{2\pi}}\left(\frac{1}{x(\alpha)}\right)\exp\left(-\left(\frac{1}{2}\right)\left(\frac{\lambda - l(\alpha)}{x(\alpha)}\right)^2\right)$$

Selectivity at length $\lambda \le S_{g,4,e(y|g)}$ (ascending limb), conditional on gear type and year:

$$s(\lambda|g,y) = S_{g,1,e(y|g)} + (1 - S_{g,1,e(y|g)})\left(\frac{\dfrac{1}{1+\exp\left(- S_{g,3,e(y|g)}(\lambda - S_{g,2,e(y|g)})\right)} - \dfrac{1}{1+\exp\left(- S_{g,3,e(y|g)}(\lambda_{min} - S_{g,2,e(y|g)})\right)}}{\dfrac{1}{1+\exp\left(- S_{g,3,e(y|g)}(S_{g,4,e(y|g)} - S_{g,2,e(y|g)})\right)} - \dfrac{1}{1+\exp\left(- S_{g,3,e(y|g)}(\lambda_{min} - S_{g,2,e(y|g)})\right)}}\right)$$

Selectivity at length $\lambda \ge S_{g,4,e(y|g)}$ (descending limb), conditional on gear type and year:

$$s(\lambda|g,y) = 1 + (1 - S_{g,5,e(y|g)}) \left(\frac{\frac{1}{1+\exp\left(-S_{g,7,e(y|g)}(\lambda - S_{g,6,e(y|g)})\right)} - \frac{1}{1+\exp\left(-S_{g,7,e(y|g)}(S_{g,4} - S_{g,6,e(y|g)})\right)}}{\frac{1}{1+\exp\left(-S_{g,7,e(y|g)}(\lambda_{max} - S_{g,6,e(y|g)})\right)} - \frac{1}{1+\exp\left(-S_{g,7,e(y|g)}(S_{g,4,e(y|g)} - S_{g,6,e(y|g)})\right)}} \right)$$

<u>Numbers at Age</u>

Matrix for converting numbers at length into numbers at age:

$$z_{a,i,j} = \frac{\int_{l_{min}(j)}^{l_{min}(j+1)} h(\lambda\,|\,a + t_{dur}(i))\,\mathrm{d}\lambda}{\int_{\lambda_{min}}^{\lambda_{max}} h(\lambda\,|\,a + t_{dur}(i))\,\mathrm{d}\lambda}$$

For all y :

$$n_{a_{min},y,1} = R_y$$

For all $a>a_{min}$:

$$n_{a,1,1} = N_a$$

For all $i<i_{max}$:

$$n_{a,y,i+1} = n_{a,y,i} \sum_{j=1}^{j_{max}} \left(z_{a,i,j} \exp\left(\left(-M - \sum_{g=1}^{g_{max}} F_{g,y,i}\, s(l_{mid}(j)|g,y) \right) t_{dur}(i) \right) \right)$$

For all $a<a_{max}$ and all $y<y_{max}$:

$$n_{a+1,y+1,1} = n_{a,y,i_{max}} \sum_{j=1}^{j_{max}} \left(z_{a,i_{max},j} \exp\left(\left(-M - \sum_{g=1}^{g_{max}} F_{g,y,i_{max}}\, s(l_{mid}(j)|g,y) \right) t_{dur}(i_{max}) \right) \right)$$

For all $y<y_{max}$:

$$n_{a_{max},y+1,1} = n_{a_{max}-1,y,i_{max}} \sum_{j=1}^{j_{max}} \left(z_{a_{max}-1,i_{max},j} \exp\left(\left(-M - \sum_{g=1}^{g_{max}} F_{g,y,i_{max}} s(l_{mid}(j)|g,y) \right) t_{dur}(i_{max}) \right) \right)$$

$$+ n_{a_{max},y,i_{max}} \sum_{j=1}^{j_{max}} \left(z_{a_{max},i_{max},j} \exp\left(\left(-M - \sum_{g=1}^{g_{max}} F_{g,y,i_{max}} s(l_{mid}(j)|g,y) \right) t_{dur}(i_{max}) \right) \right)$$

At time of spawning:

$$u_{a,y} = n_{a,y,i_{spa}} \sum_{j=1}^{j_{max}} \left(z_{a,i_{spa},j} \exp\left(\left(-M - \sum_{g=1}^{g_{max}} F_{g,y,i_{spa}} s(l_{mid}(j)|g,y) \right) \left(\tau_{spa} - \sum_{i=1}^{i_{spa}-1} t_{dur}(i) \right) \right) \right)$$

At time of survey:

$$v_{a,y} = n_{a,y,i_{sur}} \sum_{j=1}^{j_{max}} \left(z_{a,i_{sur},j} \exp\left(\left(-M - \sum_{g=1}^{g_{max}} F_{g,y,i_{sur}} s(l_{mid}(j)|g,y) \right) \left(\tau_{sur} - \sum_{i=1}^{i_{sur}-1} t_{dur}(i) \right) \right) \right)$$

Biomass

Start-of-year biomass at ages $a > a_{rec}$:

$$b_y = \sum_{a=a_{rec}}^{a_{max}} \left(n_{a,y,1} \sum_{j=1}^{j_{max}} z_{a,1,j} w(l_{mid}(j)) \right)$$

Female spawning biomass:

$$c_y = \frac{1}{2} \sum_{a=a_{min}}^{a_{max}} \left(u_{a,y} \sum_{j=1}^{j_{max}} z_{a,i_{spa},j} w(l_{mid}(j)) p(l_{mid}(j)) \right)$$

Survey biomass:

$$d_y = Q \sum_{a=a_{min}}^{a_{max}} \left(v_{a,y} \sum_{j=1}^{j_{max}} z_{a,i_{sur},j} w(l_{mid}(j)) s(l_{mid}(j)|g_{sur},y) \right)$$

Appendix 2B: Comparison of Shelf and Slope Survey Size Compositions

At its November, 2001 meeting, the BSAI Groundfish Plan Team requested that "the authors examine the slope trawl survey and longline survey data, tabulating the proportion of cod by size class outside the shelf trawl survey frame and evaluating whether dome-shaped selectivity is reasonable for the shelf survey." Figures 2B1 and 2B2 provide the requested information.

Figure 2B1 compares the size compositions of the bottom trawl shelf and longline surveys from the five most recent surveys for which data are available (1992, 1993, 1994, 1997, and 1999). In those years, the longline survey did not sample depths less than 200 meters, whereas the bottom trawl shelf survey did not sample depths greater than 200 meters. Figure 2B1 shows a fairly distinct difference in the size compositions from the two surveys in all five years, with the longline survey consistently yielding a higher mean size than the bottom trawl shelf survey. This evidence would be consistent with a hypothesis that the bottom trawl shelf survey does not sample a portion of the population consisting of relatively large fish residing on the slope.

The upper panel of Figure 2B2 compares the size compositions of the bottom trawl shelf and slope surveys for 2002. As with Figure 2B1, this panel shows a fairly distinct difference in the size compositions from the two surveys, with the slope survey yielding a higher mean size than the shelf survey. Again, this evidence would be consistent with a hypothesis that the bottom trawl shelf survey does not sample a portion of the population consisting of relatively large fish residing on the slope.

Per the Plan Team's request, Figure 2B1 and the upper panel of Figure 2B2 deal with the size composition in terms of proportions. Absent estimates of survey catchability and selectivity, a proportional representation is the most appropriate. No estimates of the longline survey's catchability or selectivity were available for this analysis. However, bottom trawl surveys are often assumed to exhibit unit catchability. If this assumption is appropriate for the bottom trawl slope survey, and if it is also assumed that the selectivity of this survey is unity for all size groups, it is possible to determine whether the size composition observed by the bottom trawl slope survey can "account" for the strongly dome-shaped selectivity curve currently estimated for the bottom trawl shelf survey. To this end, the lower panel of Figure 2B2 shows the proportion of the total (shelf plus slope) population that would be represented by the slope portion of the population given the assumptions of unit catchability and selectivity for the bottom trawl slope survey. As the lower panel of Figure 2B2 shows, the slope survey never accounts for more than 3% of the total in any size bin. Therefore, this simple analysis based on two very strong assumptions would not corroborate a hypothesis that the dome-shaped selectivity curve currently estimated for the bottom trawl shelf survey is due entirely to large fish residing on the slope at the time of the shelf survey.

The Plan Team's request raises the question of what constitutes a "reasonable" selectivity estimate. Traditionally, assessments of the BSAI Pacific cod stock have viewed a parameter estimate as reasonable if it provided the best fit to the data, unless such an estimate appeared dramatically inconsistent with more direct estimates or with well established estimates of the same parameter for similar stocks. The data seem to indicate that the early-season trawl fishery selects large fish that the bottom trawl shelf survey does not. This does not necessarily mean that these large fish are outside the survey area. As conceptualized in most stock assessment models, selectivity is an expression of a complex combination of factors, including configuration and performance of the gear, timing of capture, location of capture, and the objectives of those deploying the gear (e.g., to maximize capture of the most profitable size groups, to achieve a statistically random sample, etc.). At present, a mechanistic model of how these factors interact to produce the quantity known as "selectivity" is not available. However, plans for future assessments of the BSAI Pacific cod stock call for a model that treats population dynamics on a much finer spatio-temporal scale than at present, which may help to provide a more mechanistic description of the selection process.

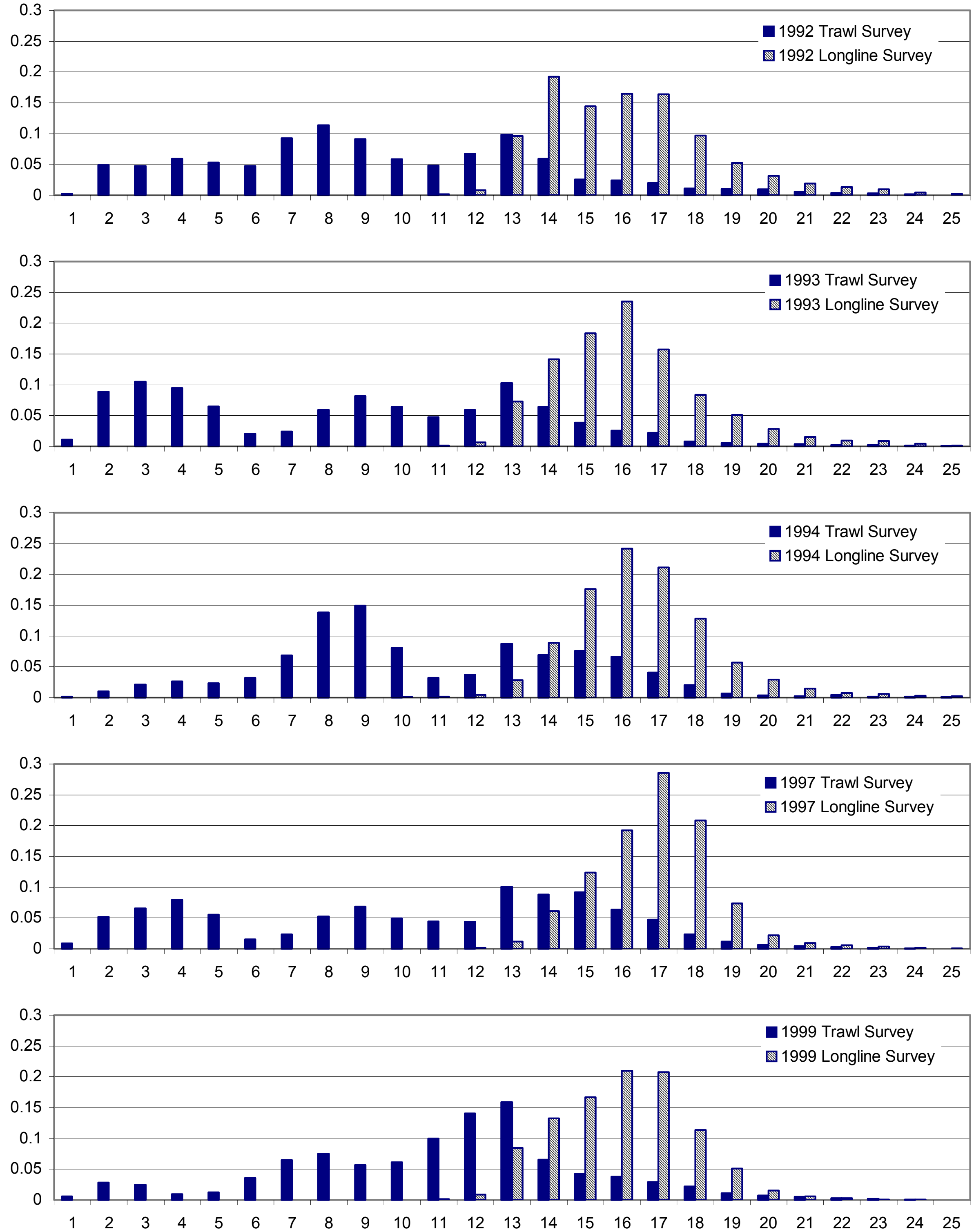


Figure 2B1–Size compositions of the bottom trawl shelf and longline surveys from the five most recent surveys for which data are available. Horizontal axis = length bin (see main text), vertical axis = proportion.

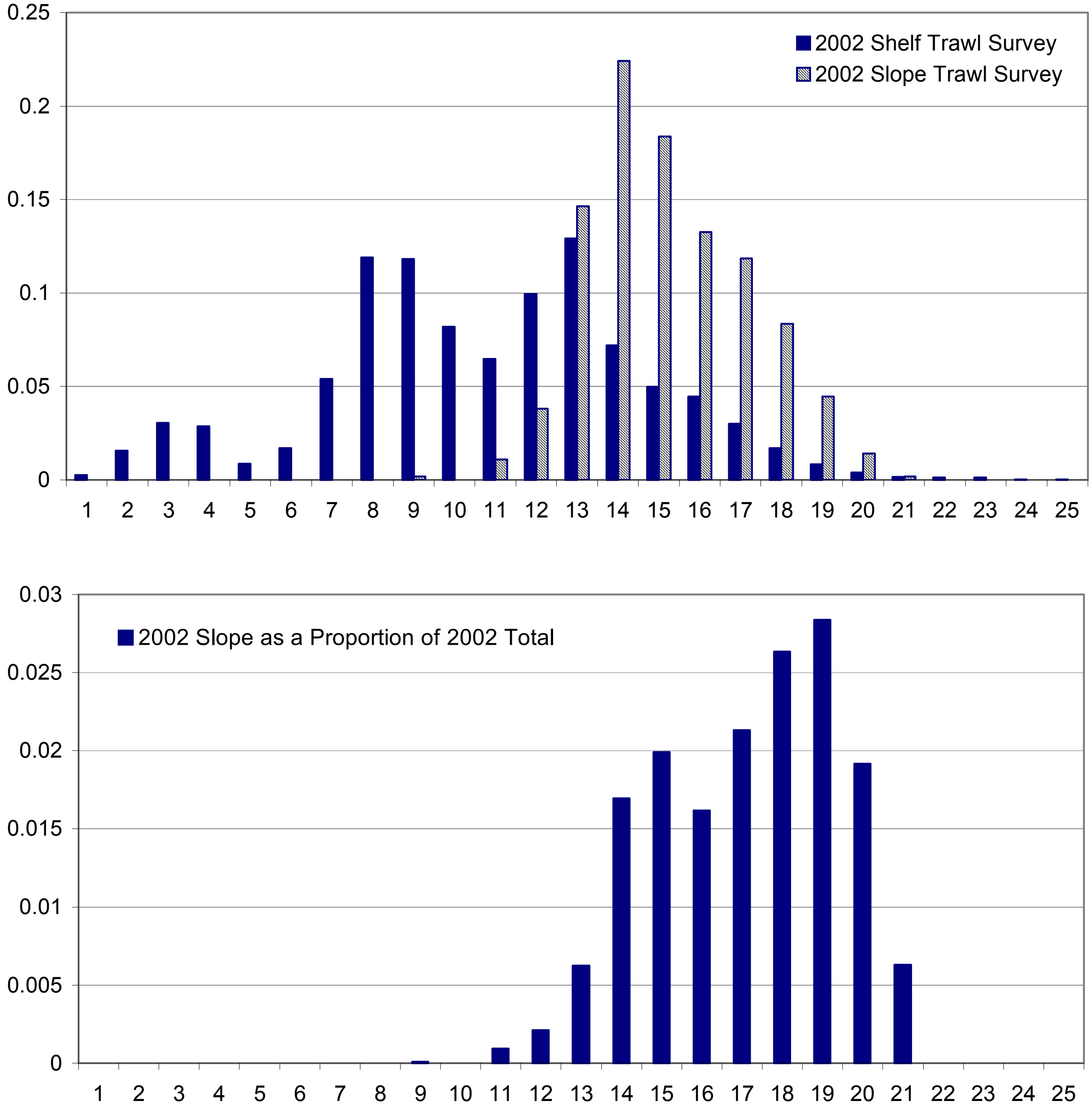


Figure 2B2–Upper panel: Size compositions of the bottom trawl shelf and slope surveys for 2002. Horizontal axis = length bin (see main text), vertical axis = proportion. Lower panel: Numbers at length from the 2002 bottom trawl slope survey expressed as a proportion of the combined numbers at length from the 2002 bottom trawl shelf and slope surveys. Horizontal axis = length bin (see main text), vertical axis = proportion.